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SID 62-557-1

FIRST QUARTERLY RELIABILITY STATUS REPORT (U)

(NAS 9-150)

30 April 1962 4.5.4.7

Approved by

J. W. Paup
Vice President and Apollo Program Manager

[redacted]

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NORTH AMERICAN AVIATION, INC.
SPACE and INFORMATION SYSTEMS DIVISION

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FOREWORD

The Quarterly Reliability Status Report is submitted in accordance with the Apollo documentation requirements delineated in NASA contract NAS 9-150; paragraph 4.5.4.7 of "Project Apollo Spacecraft Development Statement of Work," Part 4, dated December 18, 1961; and paragraph 3.4.3 of MIL-R-27542. The information contained herein covers the period from 1 January through 31 March 1962.

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CONTENTS

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ILLUSTRATIONS

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TABLES

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INTRODUCTION

This document is the first in a series of comprehensive reliability status and crew safety program reports for the Apollo Project. Significant accomplishments made from 1 January through 31 March 1962 are delineated in Section I; planned activities through 30 June 1962 are outlined in Section II. Accomplishments in various organizational and technical areas, significant problems and methods for resolution, and results of studies will be presented in detail in this and subsequent reports.

Subject matter selected for inclusion in these documents will permit an assessment of progress by management and technical personnel and will serve as a guide in determining necessary reorientation or concentration of attention and effort as the program develops. Use of this material as a guide will enhance accomplishment of the Apollo mission success and crew safety objectives on a timely basis.

Although this report is, of necessity, brief, considerable expansion in reported material can be anticipated in future issues.

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I. ACCOMPLISHMENTS

ORGANIZATION AND MANAGEMENT

The original reliability organization, as outlined to NASA, consisted of a reliability and crew safety manager who reported technically and administratively to Apollo Engineering. Various reliability engineers were technically responsible to the manager but were administratively responsible to the Director of Reliability Engineering in Quality Assurance. A more effective working arrangement has been achieved by reassigning the manager to Quality Assurance with administrative and technical responsibility for personnel.

Strong technical guidance is provided by locating reliability engineers in the project area to assure day-to-day contact with designers and by having the reliability manager participate in engineering staff meetings. Further emphasis on design integrity has been achieved by designating the reliability manager as a permanent member of the Apollo Design Review Board.

Major reliability management activities during the first quarter of 1962 consisted of producing the following:

1. Definitive task statements, manpower loads, schedules, and anticipated cost allocation in support of program implementation and a firm cost proposal

2. Documentation and reviews of the Reliability Program Plan (SID 62-203) and the Qualification-Reliability Test Plan (SID 62-204)

3. Additional plans for training, high-reliability parts employment, major subcontractor and associate contractor activities, and data operations

Numerous indoctrination and coordination meetings held with NASA and S&ID subcontractors are described in subsequent sections of this report.

MILESTONES

Figure 1 illustrates the major milestones scheduled for this report period. All milestones were accomplished on schedule.

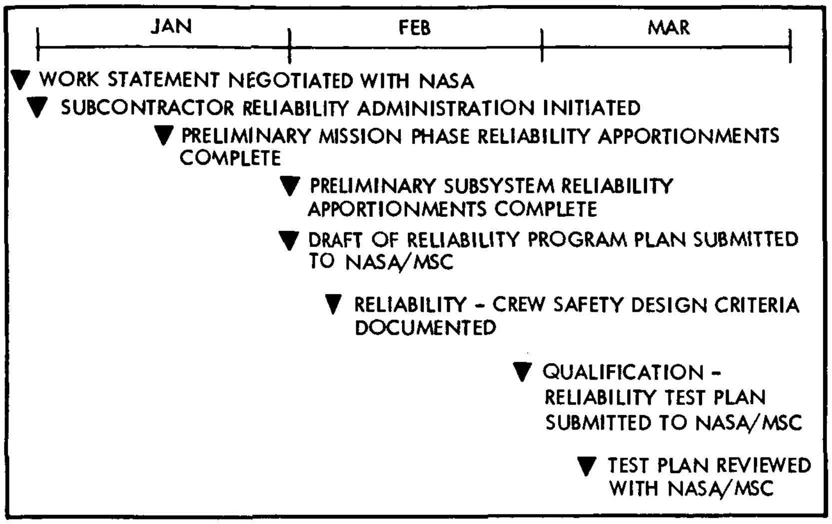

Figure 1. Major Reliability Milestones First Quarter of 1962

APPORTIONMENTS

The probabilities of success (0.90) and crew survival (0.999), as assigned by NASA for the Apollo mission, include the effects of the ground complex; the launch vehicle; the navigation and guidance system; and the Apollo command, service, and lunar landing modules. To define initial requirements for the command and service modules, these objectives were apportioned to each of the major elements by means of conventional techniques. Mission success apportionments, so derived, are 0.999 for the GOSS complex, 0.950 for the boost system (defined by NASA), 0.960 for the command and service modules, and 0.988 for the lunar landing module.

The command and service module allocation was further apportioned to each mission phase and to the functioning subsystems. Numerical allocations were based on the following considerations:

1. Operating time
2. Subsystem complexity and known redundancy
3. Environmental severity
4. Critical nature of the function or mission phase

All functioning subsystems were assumed to be series elements during a given phase with no allowance made for alternate modes of operation or on-board maintenance. The total mission time was divided into 14 time phases. The results of this study are delineated in Table 1 and will be used as a basis for preliminary apportionment to the components of each subsystem.

As additional information becomes available on the foregoing listed items and as alternate modes of operation and maintenance concepts are better defined, more precise allocations will be made.

[redacted]

Table 1. Command and Service Modules Subsystem Reliability and Crew Safety Apportionments

System / Mission Phase		Prelaunch	1st-2nd Stage Boost	Parking Orbit	Inject to Trans-lunar	Trans-lunar	Lunar Orbit and Landing	Lunar Explo-ration	Lunar Launch	Lunar Orbit	Inject to Trans-earth	Trans-earth	Reentry	Earth Landing	Recovery	Total
Time (Minutes)		240.0	8.4	58.0	6.0	3900.0	180.0	1248.0	5.9	66.0	2.0	3690.0	25.0	12.0	4320.0	13,761.3
Navigation and guidance	R	0.999969	0.999991	0.999978	0.999996	0.997478	0.999837	0.999193	0.999995	0.999983	0.999999+	0.997613	0.999974	0.999994		0.994
	P_s	0.999999+	0.999999+	0.999999+	0.999999+	0.999966	0.999998	0.999989	0.999999+	0.999999+	0.999999+	0.999968	0.999999+	0.999999+		0.99992
Stability and Control	R	0.999974	0.999993	0.999981	0.999997	0.997898	0.999864	0.999327	0.999996	0.999986	0.999999+	0.998011	0.999978	0.999995		0.995
	P_s	0.999999+	0.999999	0.999999+	0.999999+	0.999996	0.999999+	0.999998+	0.999999+	0.999999+	0.999999+	0.999996	0.999999	0.999999+		0.9999
Command module reaction control	R													0.999960		0.99996
	P_s													0.999960		0.99996
Environmental control	R	0.999972	0.999992	0.999979	0.999996	0.997696	0.999851	0.999263	0.999996	0.999984	0.999999	0.997820	0.999976	0.999994	0.998979	0.9935
	P_s	0.999998+	0.999999+	0.999999	0.999999+	0.999894	0.999993	0.999966	0.999999+	0.999999	0.999999+	0.999899	0.999999	0.999999+	0.999953	0.9997
Electrical power	R	0.999961	0.999994	0.999986	0.999998	0.998405	0.999897	0.999489	0.999997	0.999911	0.999999+	0.998491	0.999984	0.999996	0.999293	0.9955
	P_s	0.999999+	0.999999+	0.999999	0.999999+	0.999989	0.999999	0.999997	0.999999+	0.999999+	0.999999+	0.999999+	0.999999+	0.999999+	0.999995	0.99997
Structural and heat protection	R	0.999987	0.999996	0.999990	0.999998	0.998937	0.999931	0.999660	0.999998	0.999993	0.999999+	0.998994	0.999989	0.999997	0.999529	0.997
	P_s	0.999999+	0.999999+	0.999999+	0.999999+	0.999972	0.999998	0.999991	0.999999+	0.999999+	0.999999+	0.999973	0.999999+	0.999999+	0.999987	0.99995
Mechanical	R		0.9959167											0.997083		0.993
	P_s		0.999983											0.999987		0.99997
*Communications	R	0.999967	0.999991	0.999976	0.999996	0.997342	0.999828	0.999149	0.999995	0.999982	0.999999+	0.997485	0.999973	0.999993	0.998822	0.9925*
	P_s															—
Instrumentation	R	0.999981	0.999995	0.999986	0.999997	0.998476	0.999902	0.999512	0.999997	0.999989	0.999999+	0.998558	0.999984	0.999996	0.999325	0.9957
	P_s															—
Service propulsion	R								0.999999+	0.999998	0.999999+	0.999775	0.999997			0.99977
	P_s								0.999999+	0.999998	0.999999+	0.999775	0.999997			0.99977
Service module reaction control	R			0.999983	0.999997	0.998039	0.999873		0.999996	0.999987	0.999999	0.998145	0.999979			0.9960
	P_s			0.999999+	0.999999+	0.999985	0.999999+		0.999999+	0.999999+	0.999999+	0.999986	0.999999+			0.99997
*Launch escape	R		0.997800													0.9978*
	P_s		0.999950													0.99995
Earth landing	R													0.999940		0.99994
	P_s													0.999940		0.99994
Total	R	0.999844	0.995878	0.999883	0.999979	0.987001	0.999155	0.996449	0.999974	0.999831	0.999991	0.987475	0.999861	0.996955	0.997129	0.9600
	P_s	0.999994	0.999978	0.999994	0.999994	0.999802	0.999986	0.999941	0.999993	0.999992	0.999993	0.999596	0.999991	0.999882	0.999935	0.9992

Note: This analysis is for the lunar landing mission including earth landing and does not include aborts

R = Mission reliability
P_s = Probability of crew survival

*Not included in total apportionment

[redacted]

APPORTIONMENT STUDIES

During this report period, the following apportionment studies were conducted.

Electrical Power Generation and Distribution Subsystem

In order to meet the apportioned electrical subsystem reliability goal presented in Table 2, distribution provisions were considered to be entirely redundant, i.e., two independent d-c busses were employed, each supplying electrical power to the d-c load. The reliability objective for d-c distribution equipment has been established at 0.99968 and can be met by employing standard components.

Table 2. Electrical Power Generation and Distribution Subsystem Reliability Apportionments

Item	Allocation
Fuel cell pressurization	0.99820
Fuel cell assembly (3 cells)	0.99770
D-c distribution (2 busses)	0.99968
A-c generation and distribution (3 static inverters and 2 busses)	0.99999
Battery module	0.99993
Total	0.9955

The fuel cell assembly (Figure 2) is designed with three independent modules, (1) three low-pressure, non-regenerative fuel cells; (2) potable water separating equipment; and (3) associated controls and sensing devices, including provisions for controlled removal of heat to a space radiator. The reliability objective for the fuel cell assembly is 0.9977 for 400 hours of power generation. The reliability objective for each cell is estimated to be 0.868. The detailed apportionment is shown in Figure 3. The individual cell reliability objective is based on a subsystem which provides normal power with all three cells operating, normal power in the event that one of the cells should fail, and emergency power in the event that two cells should fail.

[redacted]

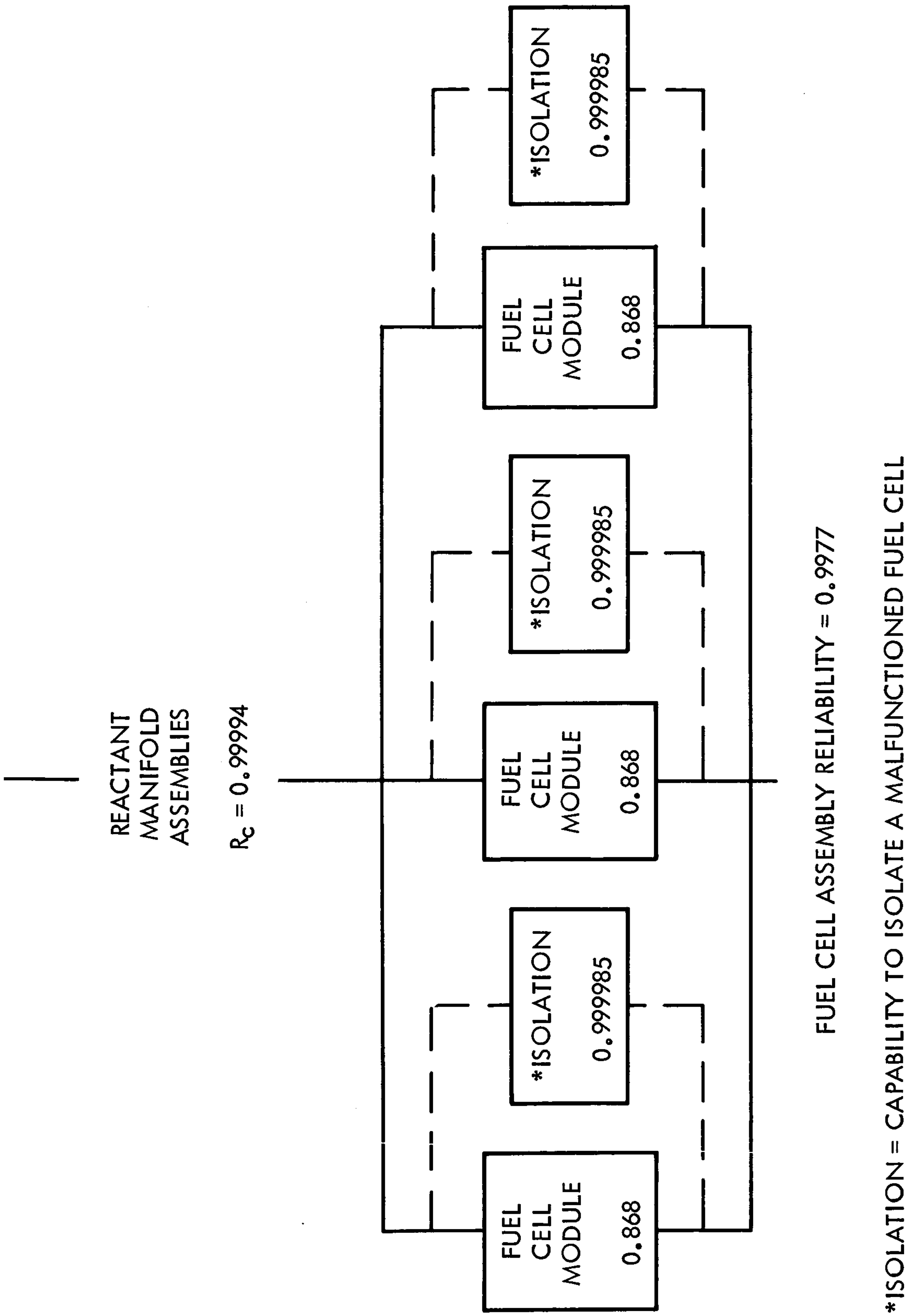

Figure 2. Fuel Cell Assembly Reliability Logic

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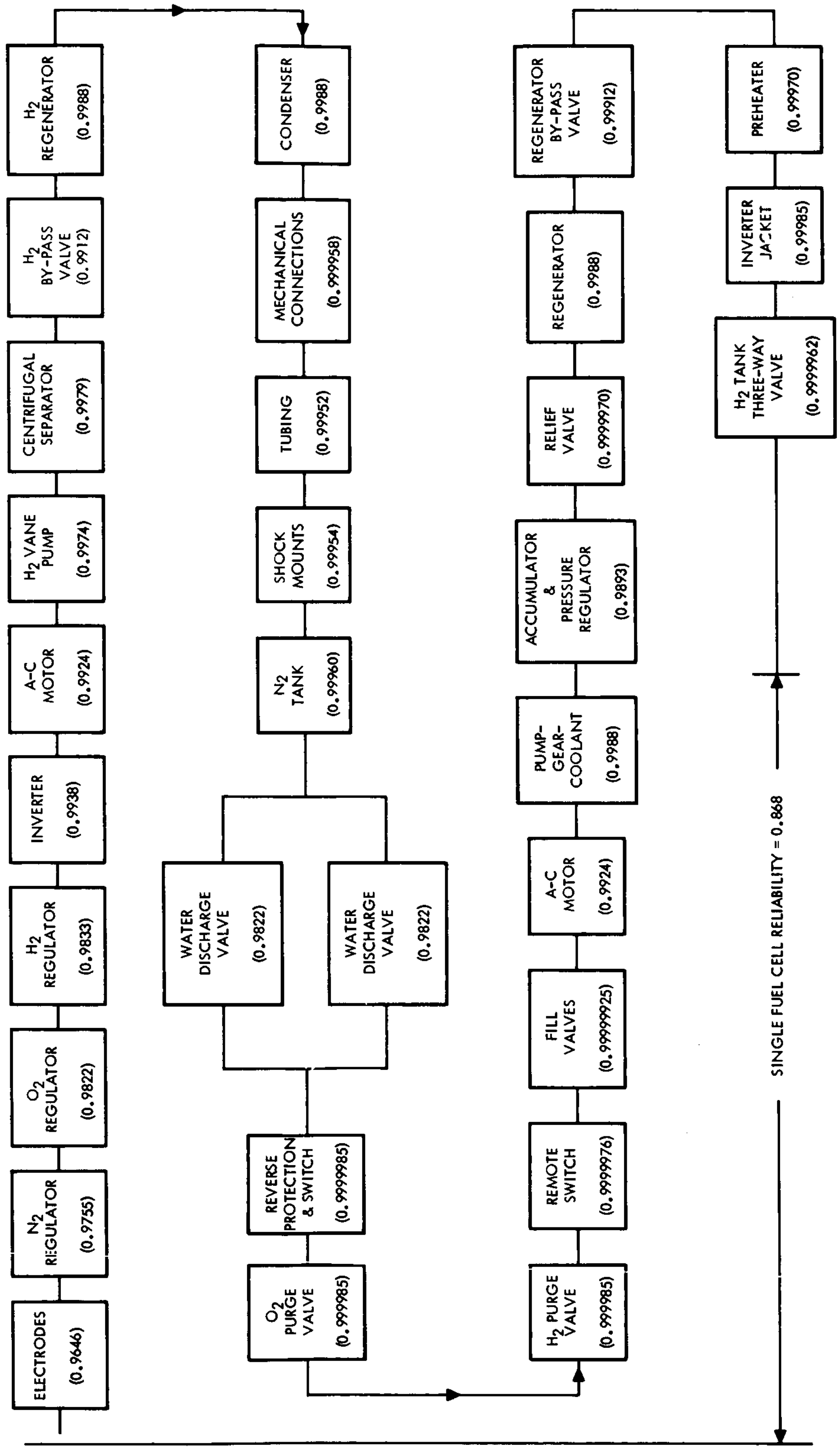

Figure 3. Single Fuel Cell Reliability Logic

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A-c generation and distribution consists of three independent static inverters and redundancy in the distribution bus. A reliability goal of 0.99999 has been apportioned to the a-c distribution function. Three static inverters, any one of which is capable of maintaining normal operation, are employed.

Environmental Control Subsystem

A reliability apportionment study was conducted for the environmental control subsystem. This subsystem is composed of six groups of items as illustrated in Figure 4. Figures 5, 6, and 7 depict the detailed apportionments for the pressure suit, water-glycol, and pressure and temperature control groups. Apportionments for the oxygen supply, water supply and, airlock pressurization groups are being derived and will be included in the next quarterly report.

Launch Escape and Tower Jettison Subsystem

The launch escape and tower jettison subsystem reliability apportionment is based on the following logic:

1. First-stage boost reliability is 0.983 (0.95 for successful three-stage boost reliability)

2. 0.995 reliability through the first 5 seconds of second-stage operation

3. 0.99995 apportioned probability that the launch escape and tower jettison subsystem operation will not exceed emergency limits.

Application of these values yield the following reliability statistics:

1. $R_{\substack{\text{Boost} \\ \text{Three stages}}} = 0.95$

   $R_{\substack{\text{Boost} \\ \text{First stage}}} = 0.983$

   Thus

   $$R_{\substack{\text{Boost} \\ \text{First stage}}} \times R_{\substack{\text{Boost} \\ \text{Second stage} \\ \text{(5 sec)}}} = 0.983 \times 0.995 - 0.978$$

   and, therefore, 22 aborts per 1000 missions might be expected.

[redacted]

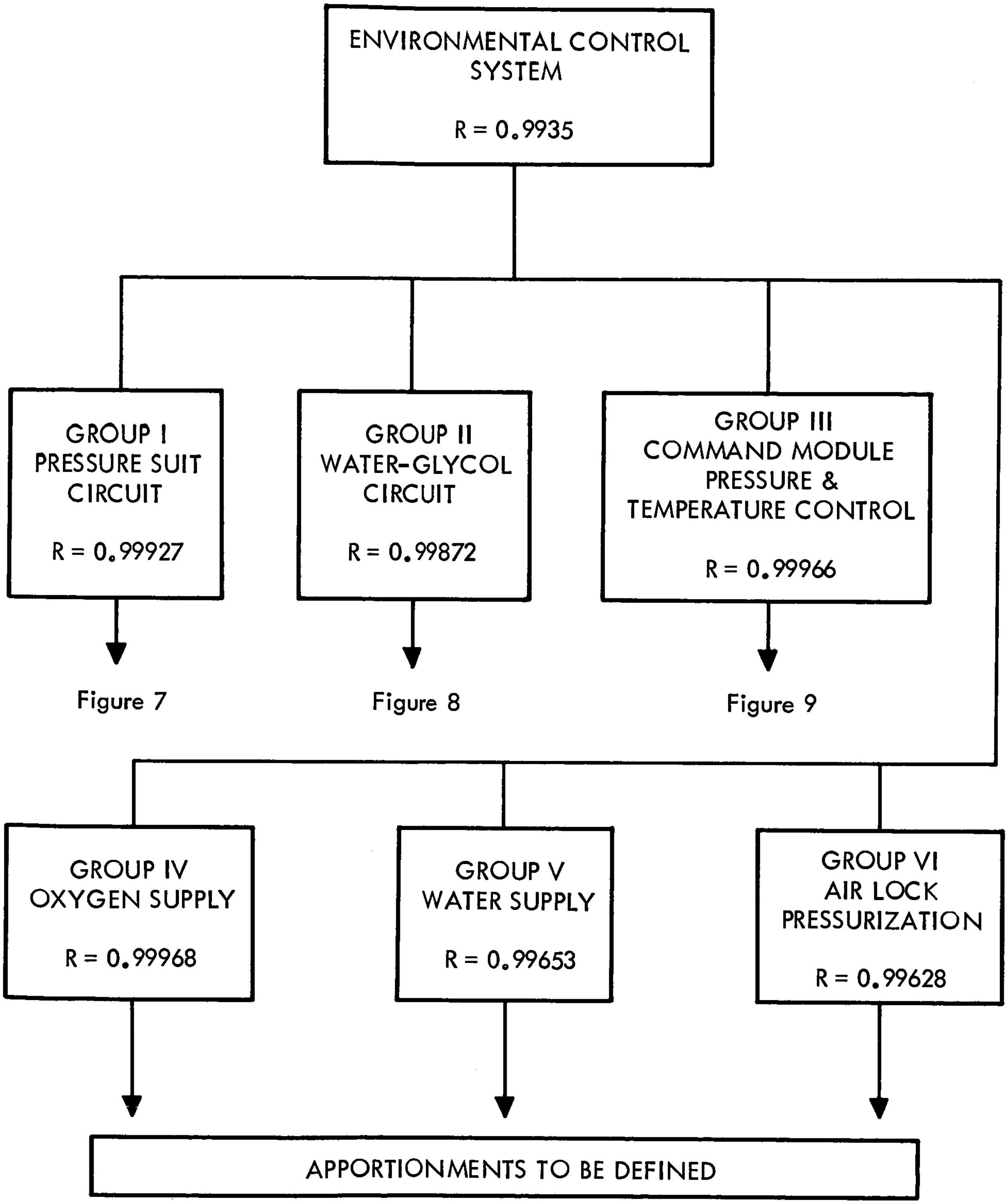
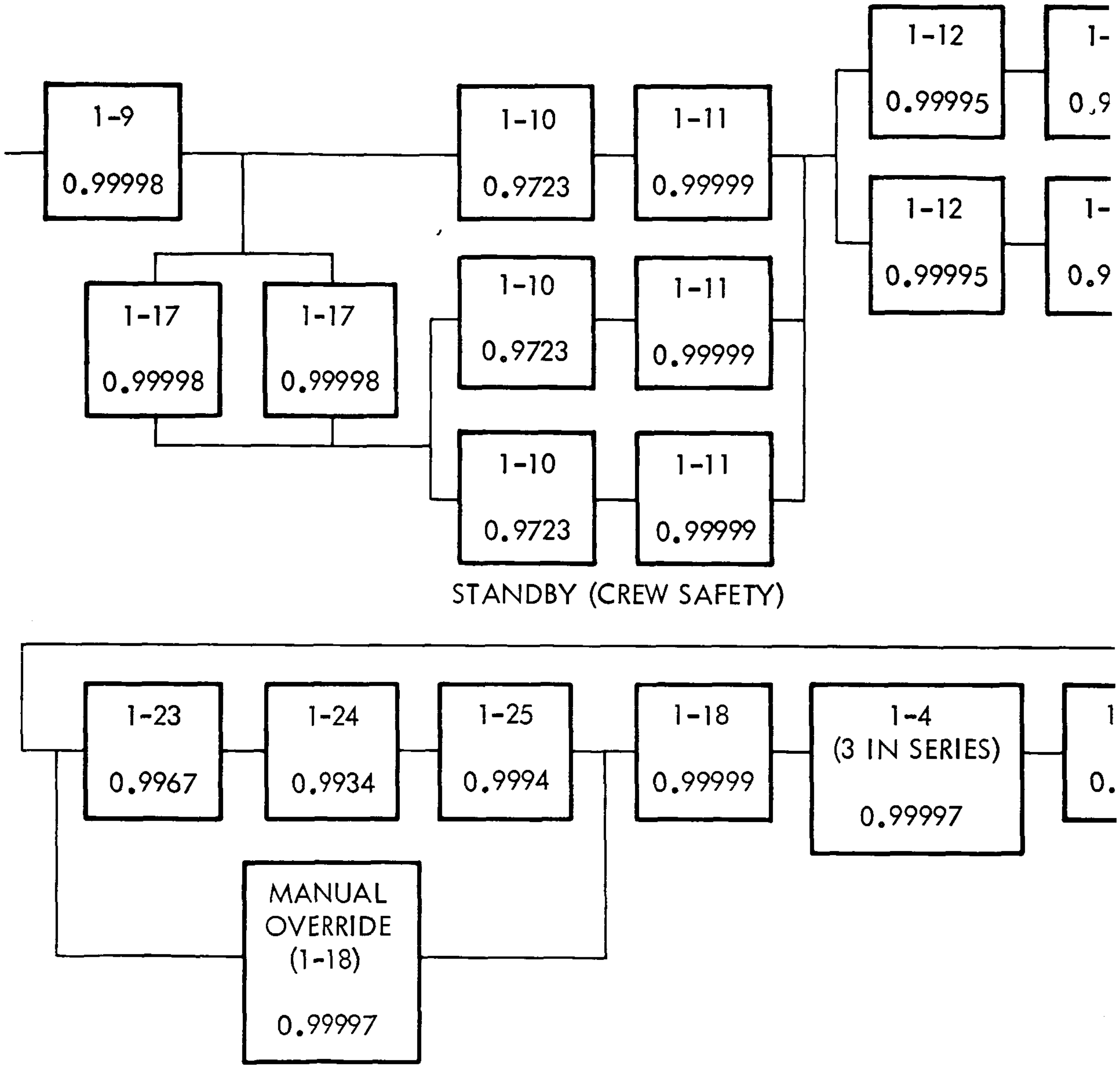


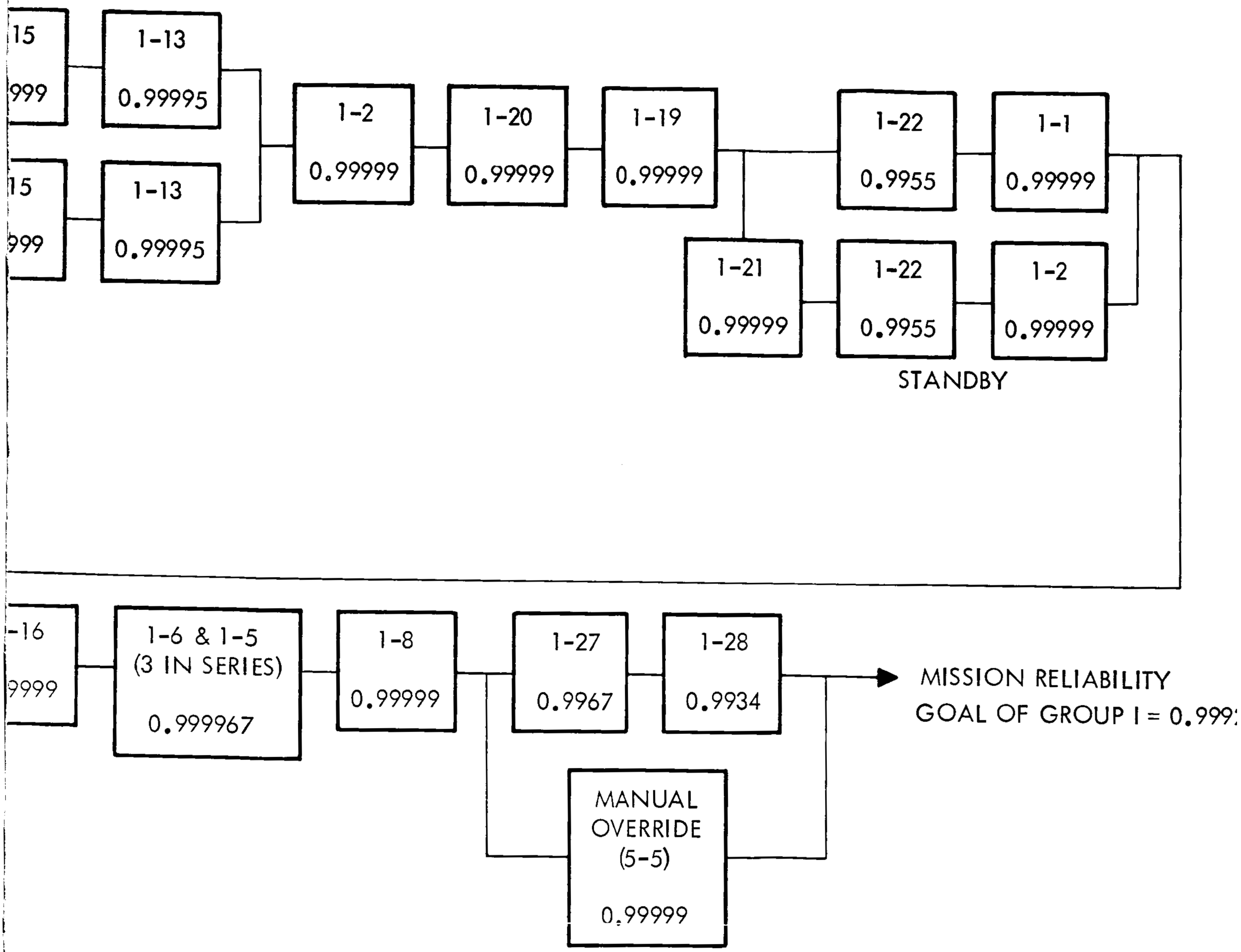
Figure 4. Environmental Control Subsystem Reliability Apportionment

[redacted]

[redacted]



1-9
0.99998
1-17
0.99998
1-17
0.99998
1-10
0.9723
1-11
0.99999
1-10
0.9723
1-11
0.99999
1-10
0.9723
1-11
0.99999
STANDBY (CREW SAFETY)
1-12
0.99995
1-12
0.99995
1-23
0.9967
1-24
0.9934
1-25
0.9994
1-18
0.99999
1-4
(3 IN SERIES)
0.99997
MANUAL
OVERRIDE
(1-18)
0.99997



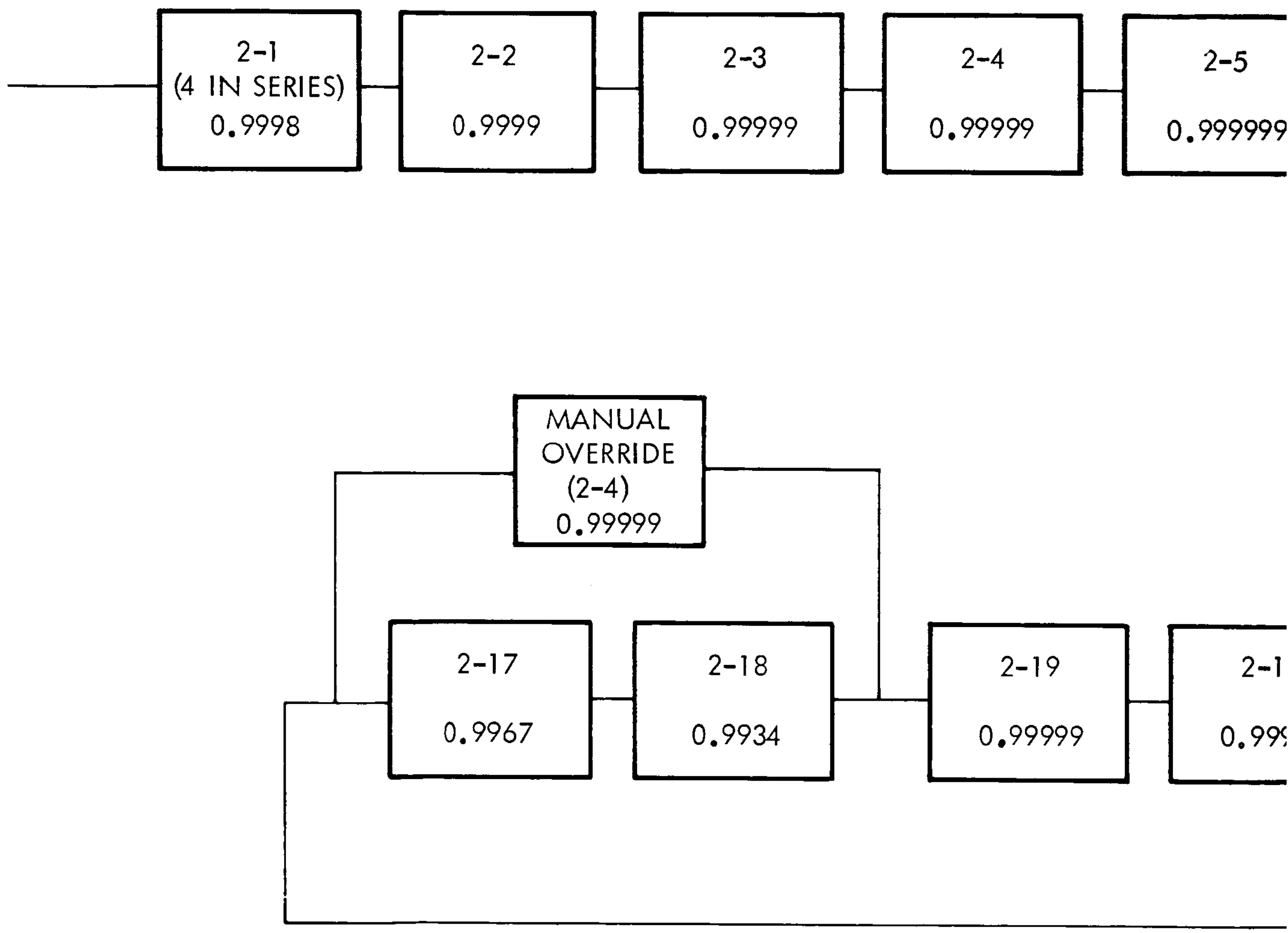
15
999
1-13
0.99995
15
999
1-13
0.99995
1-2
0.99999
1-20
0.99999
1-19
0.99999
1-22
0.9955
1-1
0.99999
1-21
0.99999
1-22
0.9955
1-2
0.99999
STANDBY
-16
9999
1-6 & 1-5
(3 IN SERIES)
0.999967
1-8
0.99999
1-27
0.9967
1-28
0.9934
MANUAL
OVERRIDE
(5-5)
0.99999
MISSION RELIABILITY
GOAL OF GROUP I = 0.999

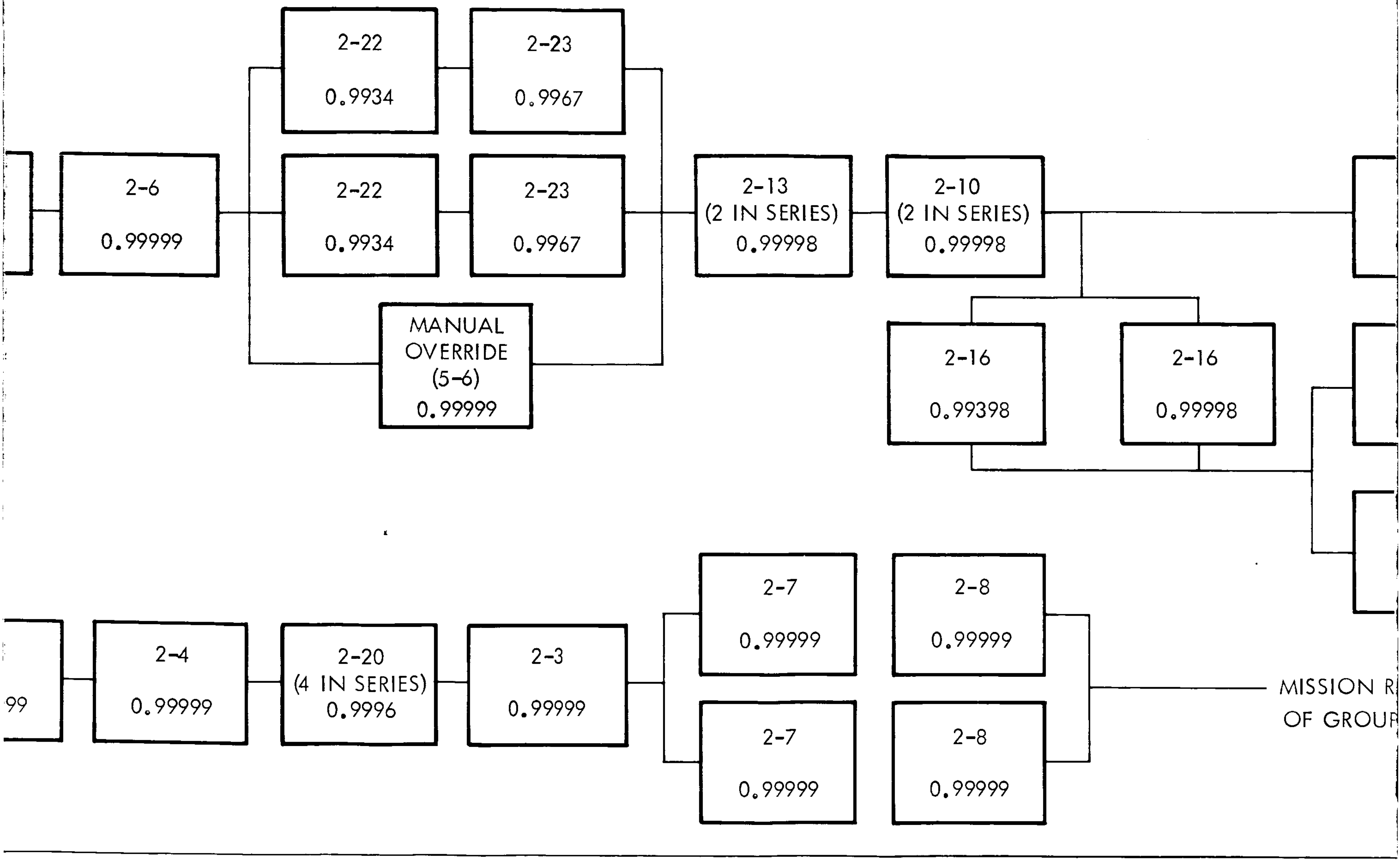
LEGEND

ITEM NO.	COMPONENT DESCRIPTION	NO. REQD	RELIABILITY PER ITEM
1-1	Water separator check valve	2	0.99999
1-2	Regenerative heat exchanger	1	0.99999
1-4	Suit flow control valve	3	0.99999
1-5	Suit flow return connection	3	0.999999
1-6	Suit manifold return check valve	3	0.99999
1-8	Debris trap	1	0.99999
1-9	Catalytic filter	1	0.99998
1-10	Suit circuit compressor	3	0.9723
1-11	Suit circuit compressor check valve	3	0.99999
1-12	CO_2 absorber isolation valve	2	0.99995
1-13	CO_2 absorber isolation valve	2	0.99995
1-15	CO_2 absorber	2	0.9999
1-16	By-pass flow control	1	0.9999
1-17	Suit compressor selector switch	2	0.99998
1-18	Regenerative heat exchanger by-pass valve	1	0.99999
1-19	Glycol-to-suit air heat exchanger	1	0.99999
1-20	Suit circuit evaporator	1	0.99999
1-21	Diverter valve	1	0.99999
1-22	Water separator	2	0.9955
1-23	Suit air inlet temperature sensor	1	0.9967
1-24	Suit air temperature control	1	0.9934
1-25	Suit air temperature selector	1	0.9994
1-27	Suit circuit evaporator temperature sensor	1	0.9967
1-28	Suit circuit evaporator temperature control	1	0.9934

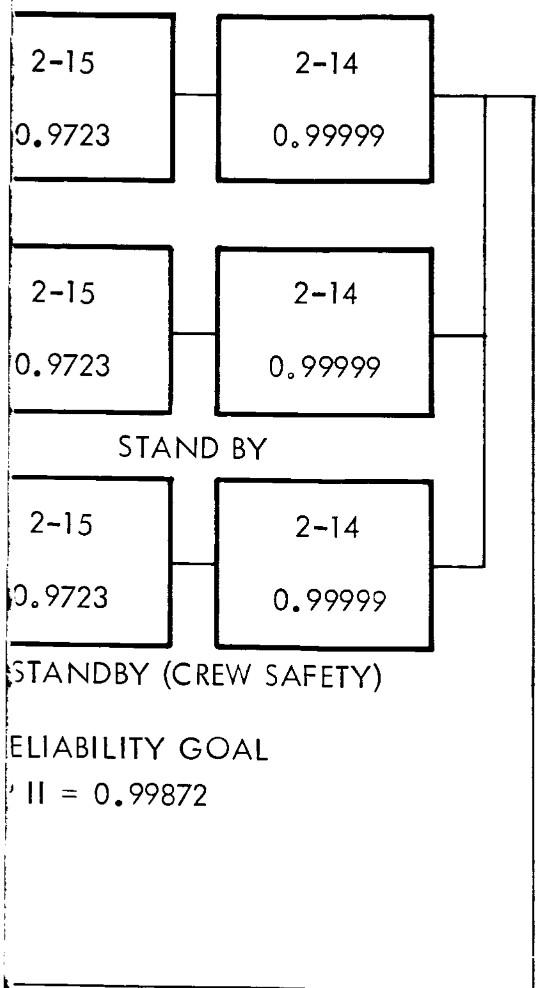
Figure 5. Pressure Suit Circuit Reliability Logic

[redacted]


2-1
(4 IN SERIES)
0.9998
2-2
0.9999
2-3
0.99999
2-4
0.99999
2-5
0.999999
MANUAL
OVERRIDE
(2-4)
0.99999
2-17
0.9967
2-18
0.9934
2-19
0.99999



2-22
0.9934
2-23
0.9967
2-6
0.99999
2-22
0.9934
2-23
0.9967
MANUAL OVERRIDE (5-6)
0.99999
2-13 (2 IN SERIES)
0.99998
2-10 (2 IN SERIES)
0.99998
2-16
0.99398
2-16
0.99998
99
2-4
0.99999
2-20 (4 IN SERIES)
0.9996
2-3
0.99999
2-7
0.99999
2-8
0.99999
2-7
0.99999
2-8
0.99999
MISSION R
OF GROUP

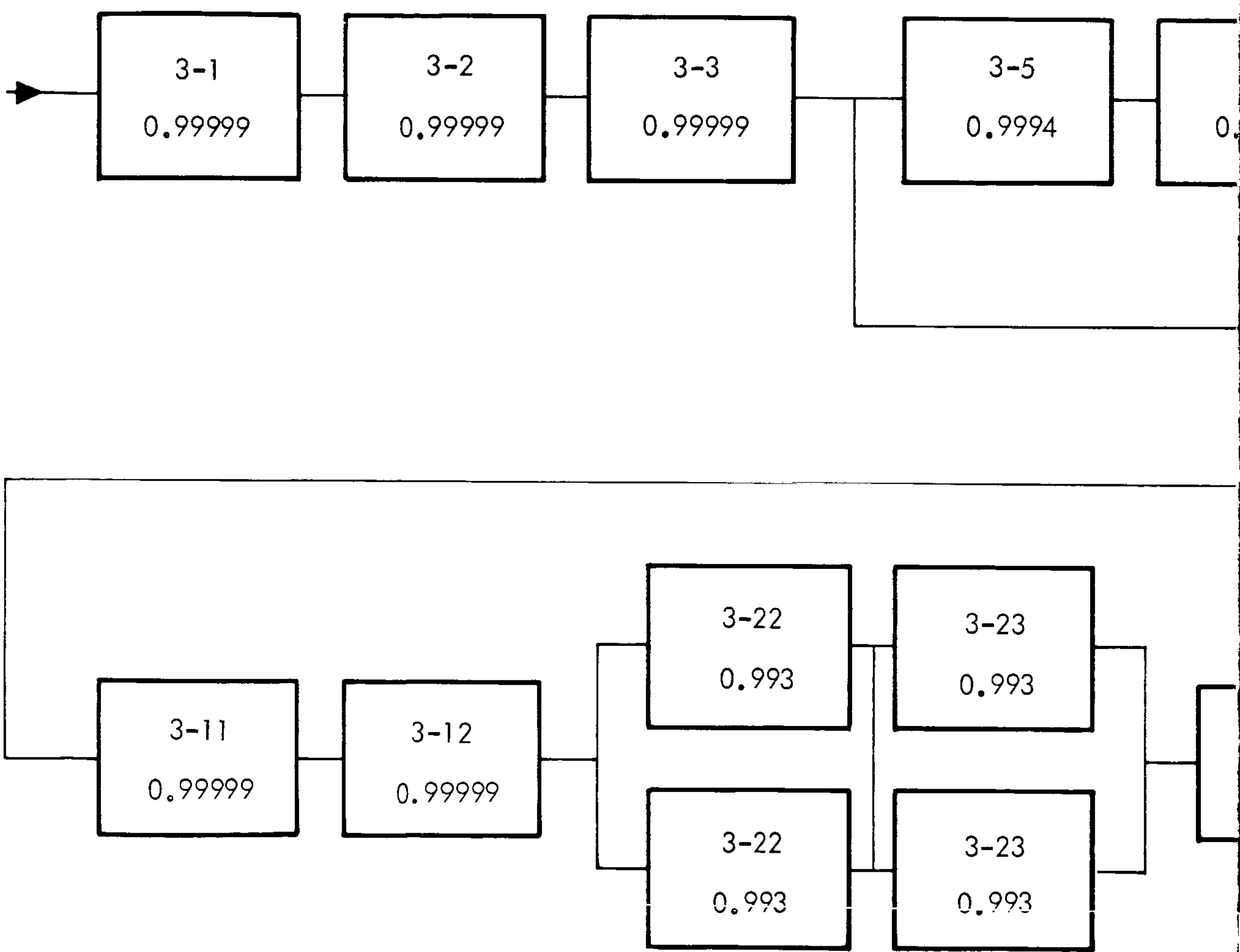


LEGEND

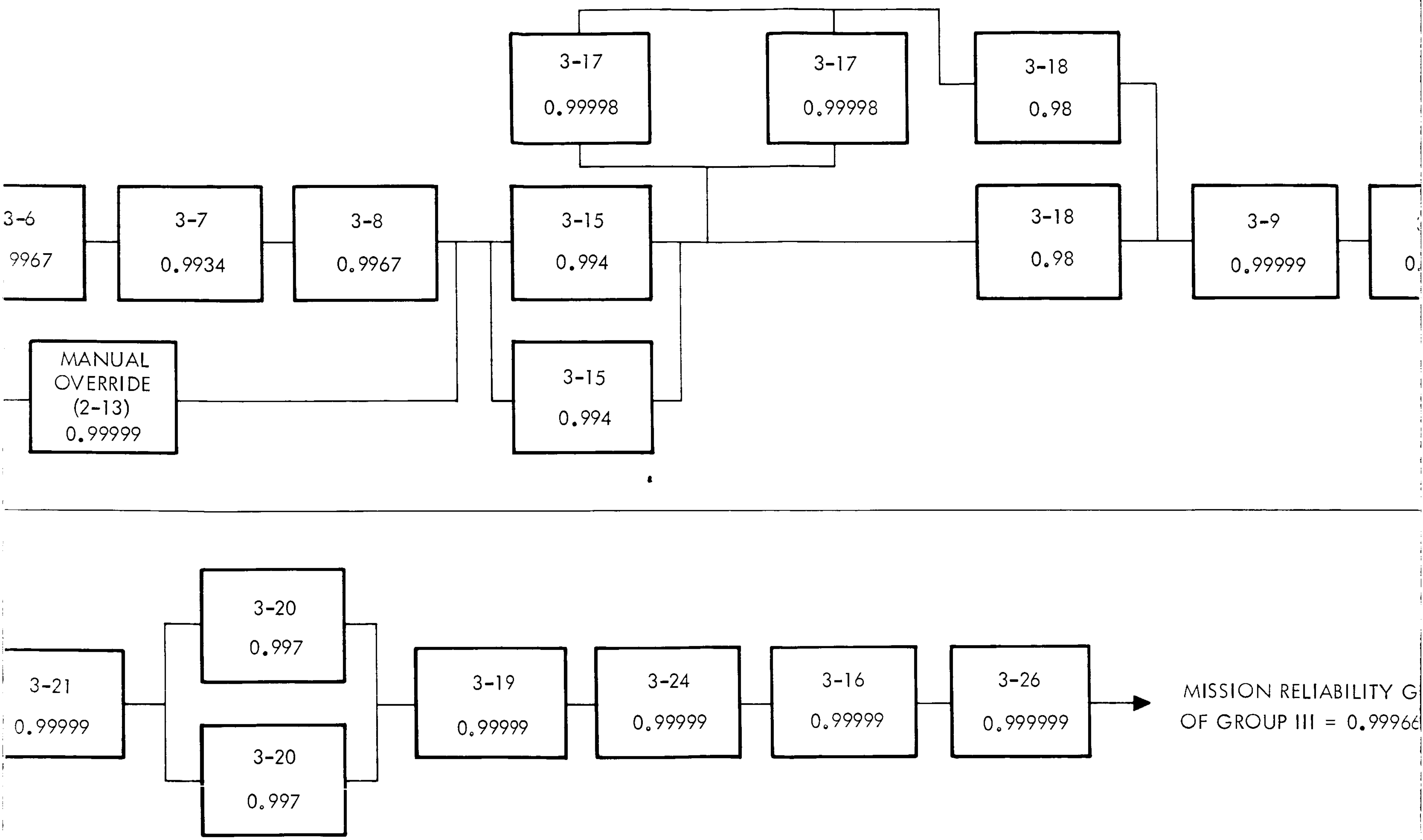
NO. ITEM	COMPONENT DESCRIPTION	NO. REQD	RELIABILITY PER ITEM
2-1	Space radiator outlet valve	4	0.99995
2-2	Glycol loop pressure relief valve	1	0.9999
2-3	Quick disconnect and shut-off valve	2	0.99999
2-4	Manual shut-off valve	3	0.99999
2-5	Fill port connection	1	0.999999
2-6	Glycol evaporator	1	0.99999
2-7	Reservoir	2	0.99999
2-8	Reservoir isolation valve	2	0.99999
2-10	Electronic equipment glycol check valve	2	0.99999
2-11	Glycol air purge valve	1	0.99999
2-13	Cabin heat exchanger by-pass valve	2	0.99999
2-14	Glycol pump check valve	3	0.99999
2-15	Glycol pump	3	0.9723
2-16	Glycol pump selector switch	2	0.99998
2-17	Regenerature heat exhanger temperature sensor	1	0.9967
2-18	Regenerature heat exchanger temperature control	1	0.9934
2-19	Regenerature heat exchanger by-pass valve	1	0.99999
2-20	Space radiator isolation valve	4	0.9999
2-22	Glycol temperature controller	2	0.9934
2-23	Glycol temperature sensor	1	0.9967

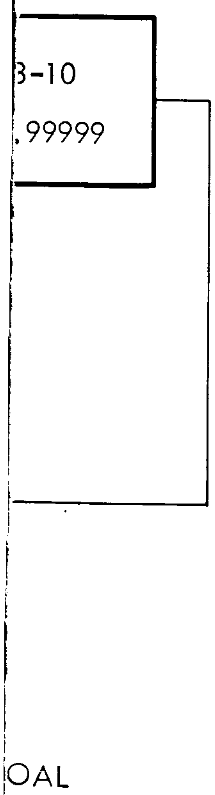
Figure 6. Water-Glycol Circuit Reliability Logic

[redacted]



3-1
0.99999
3-2
0.99999
3-3
0.99999
3-5
0.9994
3-11
0.99999
3-12
0.99999
3-22
0.993
3-23
0.993
3-22
0.993
3-23
0.993


3-17
0.99998
3-17
0.99998
3-18
0.98
3-6
9967
3-7
0.9934
3-8
0.9967
3-15
0.994
3-18
0.98
3-9
0.99999
0.
MANUAL
OVERRIDE
(2-13)
0.99999
3-15
0.994
3-21
0.99999
3-20
0.997
3-20
0.997
3-19
0.99999
3-24
0.99999
3-16
0.99999
3-26
0.999999
MISSION RELIABILITY G
OF GROUP III = 0.9996



LEGEND

ITEM NO.	COMPONENT DESCRIPTION	NO. REQD	RELIABILITY PER ITEM
3-1	Cabin outflow, pressure regulator and neg relief valve	1	0.99999
3-2	Cabin heat exchanger	1	0.99999
3-3	Cabin air shut-off valve	1	0.99999
3-5	Cabin temperature selector	1	0.9994
3-6	Cabin temperature anticipator	1	0.9967
3-7	Cabin temperature controller	1	0.9934
3-8	Cabin temperature sensor	1	0.9967
3-9	Inflow snorkel	1	0.99999
3-10	Inflow snorkel manual control valve	1	0.99999
3-11	Outflow snorkel	1	0.99999
3-12	Outflow snorkel manual control valve	1	0.99999
3-15	Cabin recirculating blower power supply	2	0.994
3-16	Back pack supply shut-off and relief valve	1	0.99999
3-17	Cabin recirculating blower selector switch	2	0.99998
3-18	Cabin recirculating blower	2	0.98
3-19	Pressure relief valve	1	0.99999
3-20	Nitrogen inflow control and flow limit valve	2	0.997
3-21	H_2 supply quick disconnect	1	0.99999
3-22	H_2 supply low-pressure regulating valve	2	0.993
3-23	N_2 supply high-pressure regulating valve	2	0.993
3-24	Back pack supply quick disconnect	1	0.99999
3-26	Back pact supply cap	1	0.999999

Figure 7. Command Module Pressure and Temperature Control Reliability Logic

[redacted]

[redacted]

2. Apportioned launch escape and tower jettison emergency limit failure probability = 0.00005, or 0.05 fatalities per 1000 missions.

3. Therefore, the subsystem reliability requirement is

$$\frac{10^3 \text{ missions}}{22 \text{ aborts}} \times \frac{0.05 \text{ fatalities}}{10^3 \text{ missions}} = \frac{0.05}{22} = 0.022 \frac{\text{fatalities}}{\text{abort}}$$

or

$$R = 1 - 0.0022 = 0.9978$$

The reliability logic diagram presented in Figure 8 illustrates the requirements for the launch escape and tower jettison subsystems and its components.

Earth Landing Subsystem

During an investigation of the feasibility of achieving the earth landing subsystem apportioned reliability goal, one problem was disclosed. The probability of jettisoning the heat shield and deploying the parachute cluster are the limiting factors in achieving the goal. Because of the series functional arrangement in the current operating concept (Figure 9) the reliability can never be greater than that for the heat shield jettison mortar (0.9999) or for deployment of the parachute cluster package (0.9998). These do not meet the system apportionment of 0.99995.

Studies of various deployment modes are being made in an attempt to eliminate this problem. One such study consists of deploying the parachutes individually. Because two parachutes afford sufficient drag to meet the required rate of descent, the deployment of the three parachutes individually increases the probability of success. This configuration creates one redundant parachute for the required two. If it is assumed that one parachute has the probability of deployment of 0.998, then the probability of two parachutes being deployed with one redundant parachute would be 0.999988. This would exceed the allocation. The configuration can be incorporated if the volume and weight constraints are not exceeded.

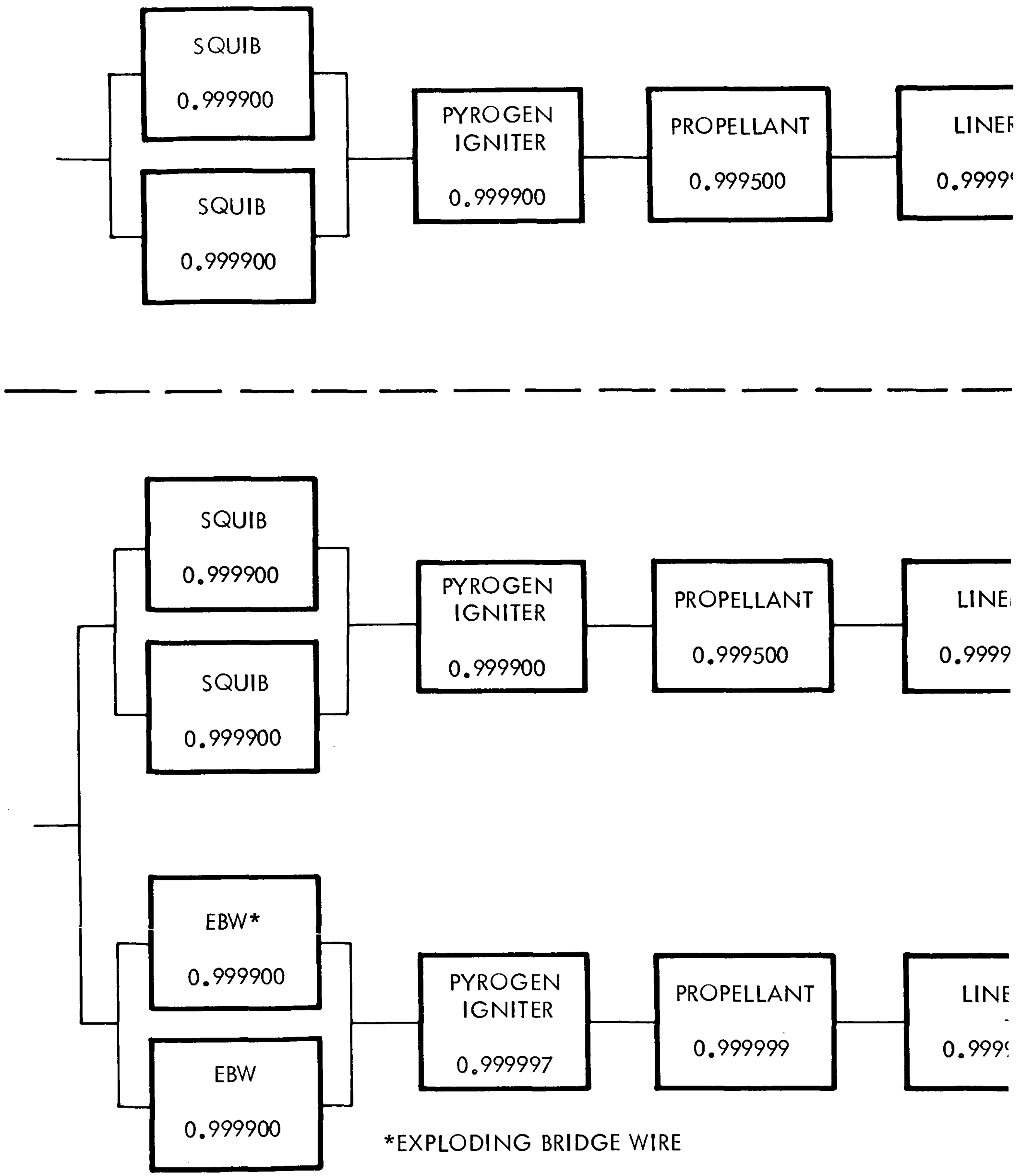
There appears to be only one way to eliminate the problem associated with the mortar for jettisoning the heat shield. Heavy concentration on design features and reliability testing are anticipated, in order to achieve the necessary product improvement.

Command Module Reaction Control Subsystem

Reliability apportionments for the command module reaction control subsystem are presented in Table 3.

[redacted]

[redacted]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PYROGEN IGNITER
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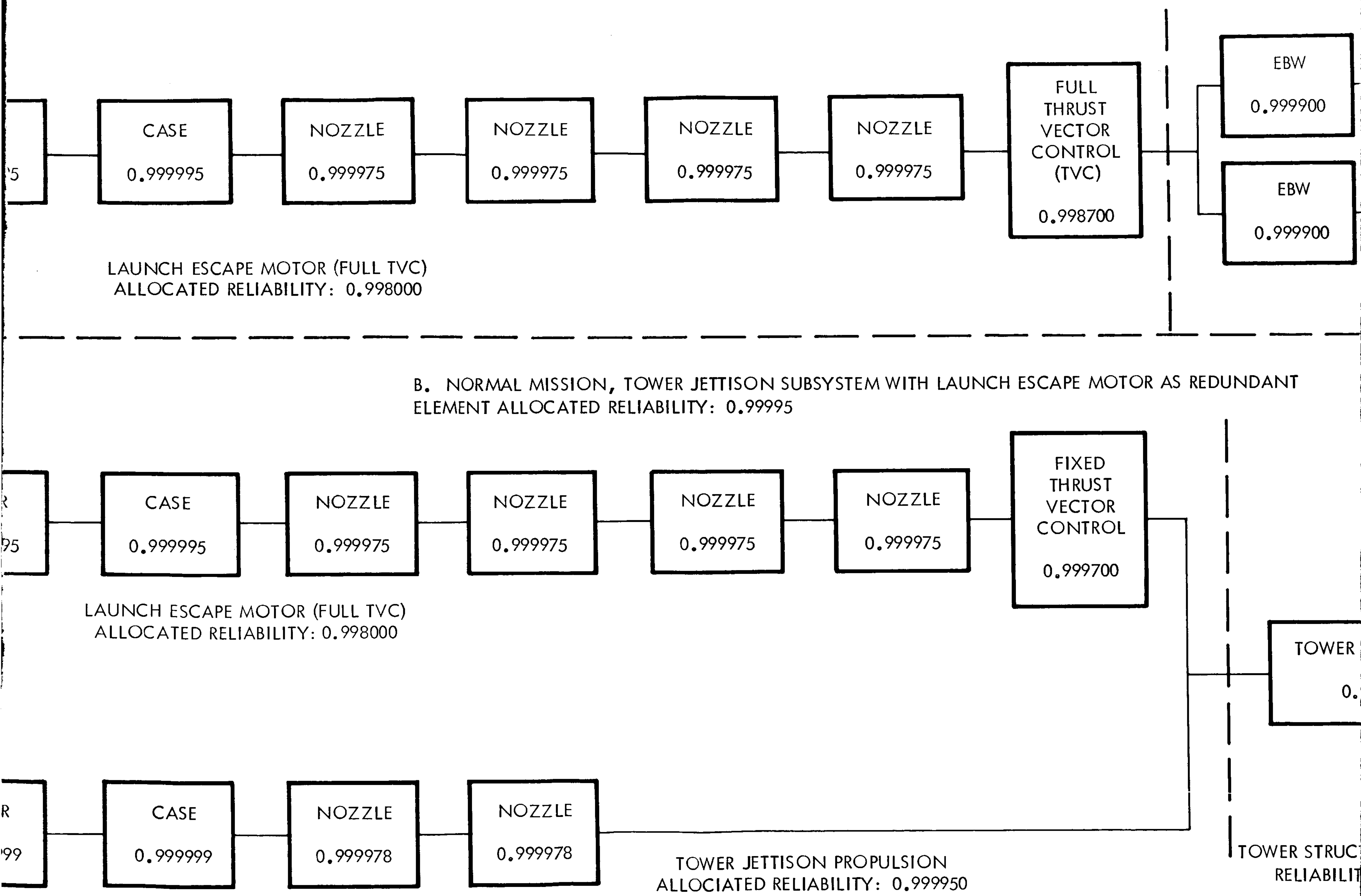
LINE
*EXPLODING BRIDGE WIRE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FULL THRUST VECTOR CONTROL (TVC)
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EBW
0.999900
EBW
0.999900
LAUNCH ESCAPE MOTOR (FULL TVC)
ALLOCATED RELIABILITY: 0.998000
B. NORMAL MISSION, TOWER JETTISON SUBSYSTEM WITH LAUNCH ESCAPE MOTOR AS REDUNDANT ELEMENT ALLOCATED RELIABILITY: 0.99995
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FIXED THRUST VECTOR CONTROL
0.999700
LAUNCH ESCAPE MOTOR (FULL TVC)
ALLOCATED RELIABILITY: 0.998000
TOWER
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TOWER JETTISON PROPULSION
ALLOCATED RELIABILITY: 0.999950
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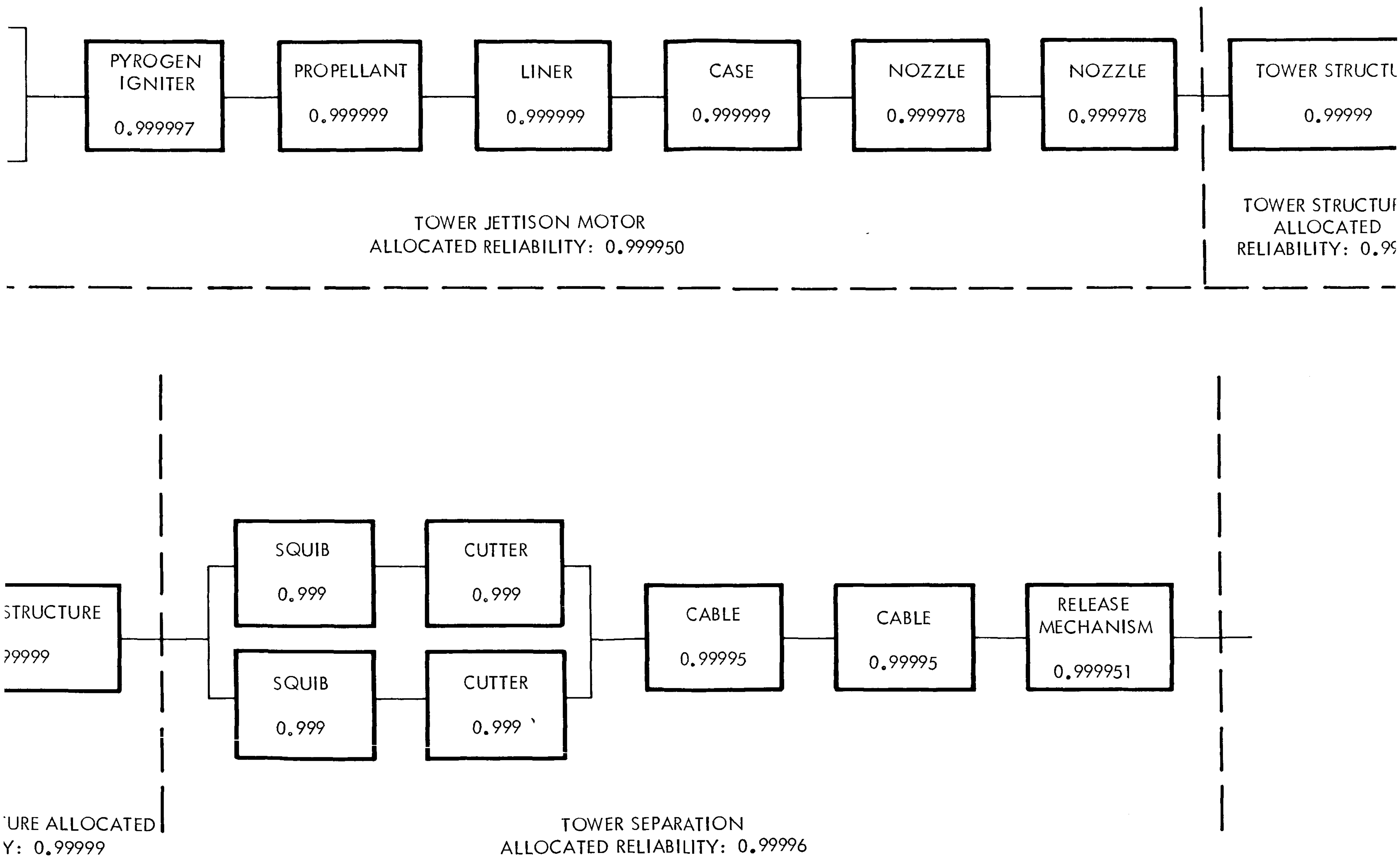
RELIABILIT

A. ABORT MISSION, LAUNCH ESCAPE SUBSYSTEM ALLOCATED RELIABILITY: 0.9978



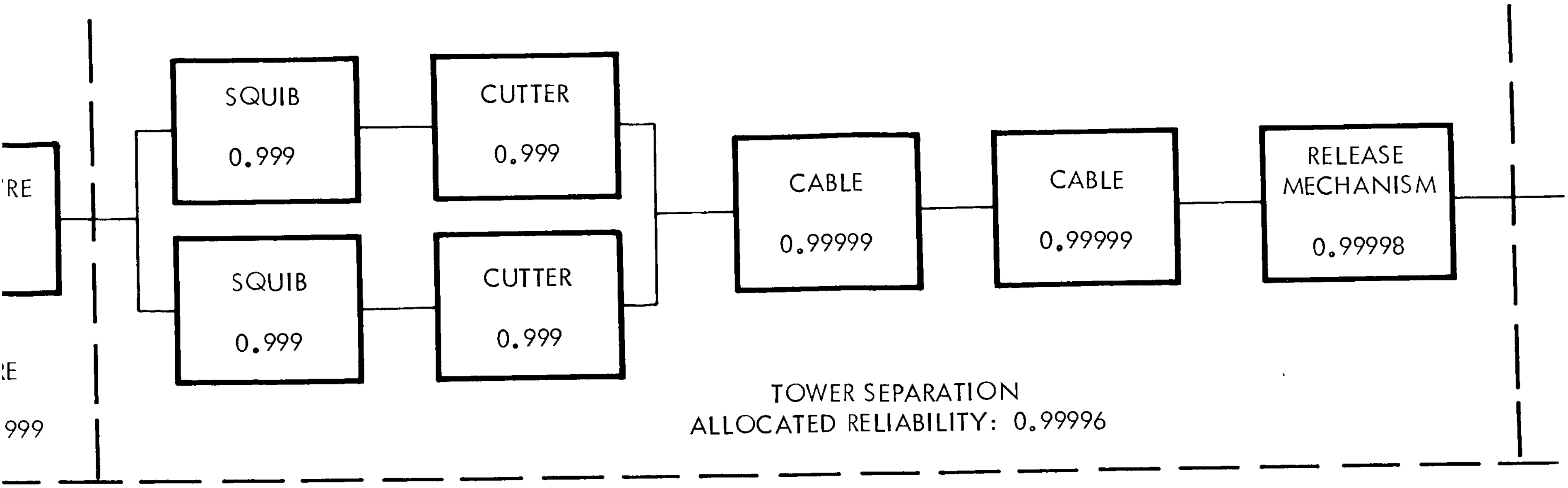


Figure 8. Launch Escape and Tower Jettison Subsystems Reliability Logic

[redacted]

[redacted]

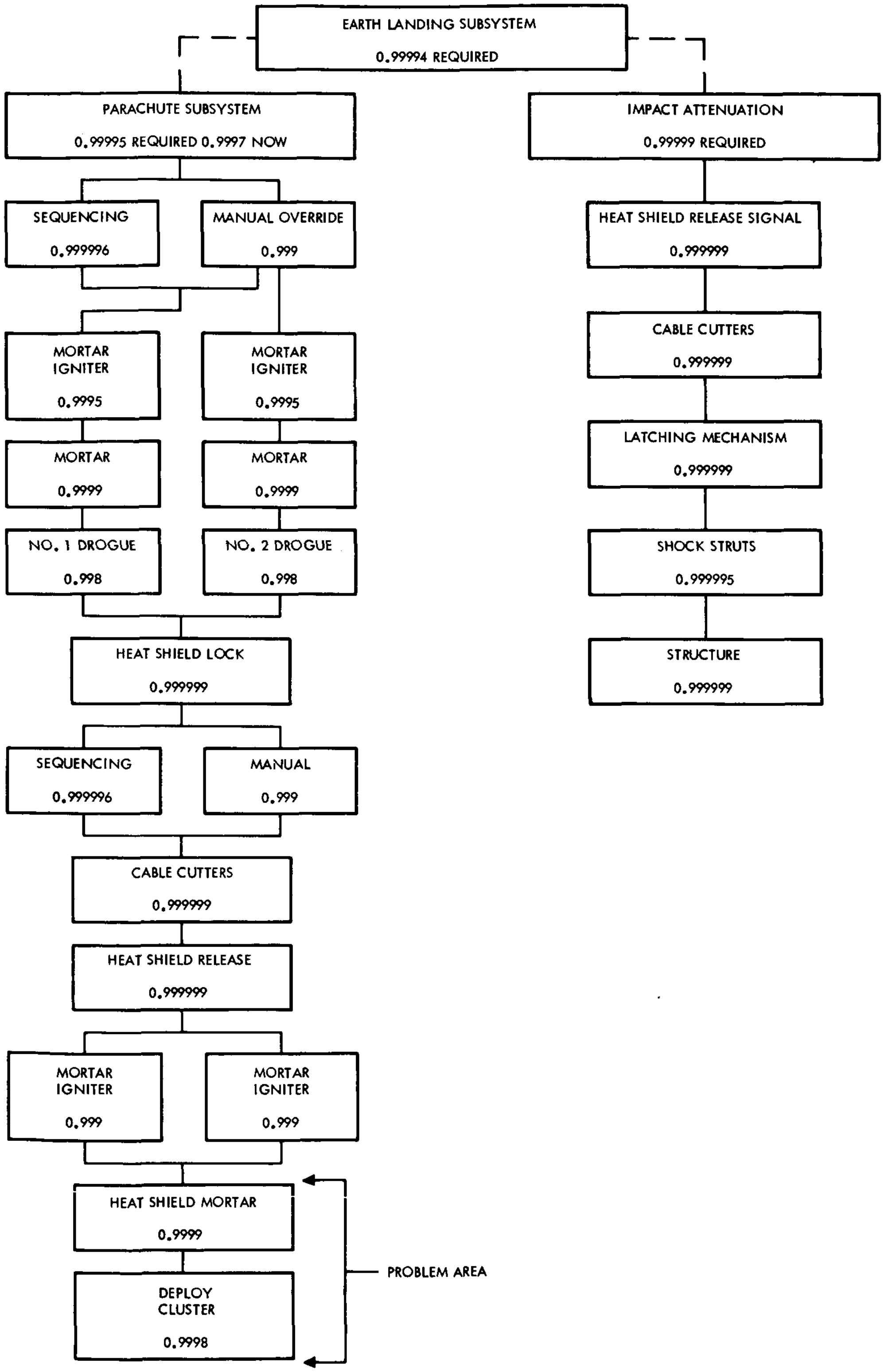


Figure 9. Earth Landing Subsystem Reliability Logic

[redacted]

[redacted]

Table 3. Command Module Reaction Control Subsystem Apportionment

Item	Reliability Apportionment			Expected Values From Experience
	Subsystem Required	Subassembly* Apportionment	Component Apportionment	
Complete subsystem	0.99996			0.999687
Pressurization		0.999985		
Helium tank			0.99997	
Fill valve			0.99993	0.999
Plug			0.99997	0.9999
Squib valve			0.99993	0.9945
Filter			0.999998	0.999945
Solenoid			0.9995	0.996
Regulator			0.9986	0.993
Tankage and Plumbing		0.999985		
Check valve			0.9995	0.9987
Relief valve			0.9995	0.9987
Propellant tank			0.9999	
Fill valve			0.99993	0.999
Solenoid			0.9995	0.996
Thrust chambers		0.999985		
Single chamber			0.999	0.964

*With redundancy shown in Figure 10.

[redacted]

The command module pressurization and propellant supply provisions (Figure 10) approach the apportioned reliability objectives by employing redundancy. Redundancy has been incorporated at the component level and again at the system level. A slight improvement in state-of-the-art reliabilities of most of the pressurization and propellant components will allow these supply provisions to meet or exceed the apportioned objectives. The positive expulsion tanks are critical items in the propellant supply because redundancy is not practical. Several methods of increasing propellant tank reliability are under consideration.

Reliability estimates, based on past experience with rocket thrust chambers, is significantly low. Redundancy has been incorporated for the reaction control engines; however, a considerable increase in state-of-the-art reliability may be required for these components.

Service Module Propulsion Subsystem

Figure 11 illustrates the service module propulsion subsystem logic diagram and the detailed reliability apportionment. Although several propellant supply designs are still being considered, the more severe failure modes were considered and a representative configuration was evaluated in detail for optimization of reliability, performance, and weight. The current reliability allocation for the service module propulsion subsystem is 0.999770. Divided into the four major elements, the apportionments are as follows:

Helium supply	0.999977
Propellant tankage	0.999883
Engine assembly	0.999930
Gimbal actuators	0.999980

As a measure of the degree of reliability growth required to meet the apportionment, a reliability prediction study was performed, based on current state-of-the-art equipment as compared to Apollo requirements. Employing this equipment, the estimated subsystem reliability would be 0.989545, indicating a failure rate deficiency of approximately 46 to 1. The greatest improvements must be in the propellant utilization and main propellant valves, in the injector, and in the combustion chamber.

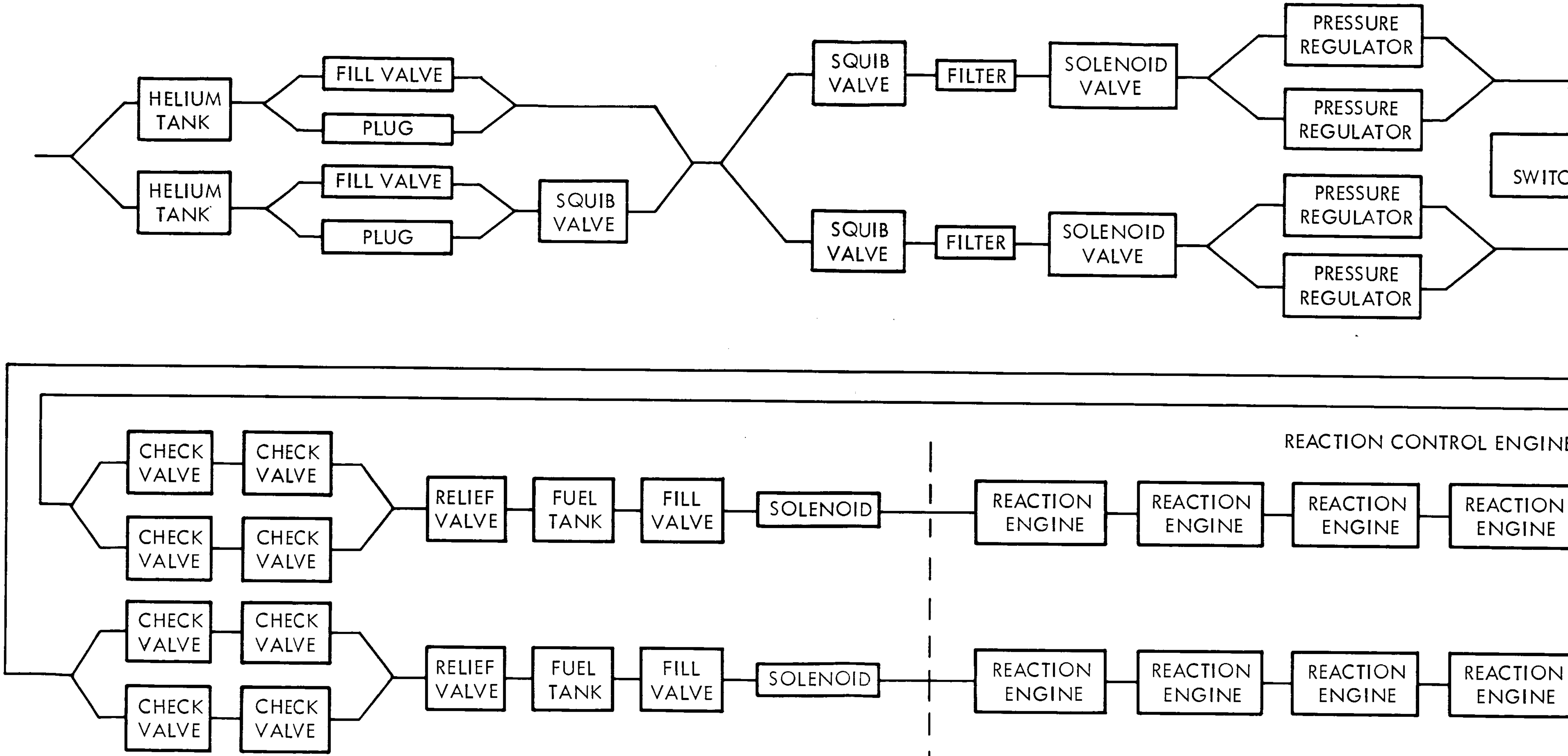
Service Module Reaction Control Subsystem

The service module reaction control subsystem (Figure 12) has incorporated redundancy at the component level and again at the subsystem level.

[redacted]

HELIUM PRESSURIZATION SYSTEM

APPORTIONED: 0.999985
ESTIMATED: 0.999850



TOTAL SYSTEM

APPORTIONED: 0.999960
ESTIMATED: 0.999687

PROPELLANT TANKAGE SYSTEM

APPORTIONED: TANKAGE & ENGINES 0.999970
ESTIMATED: TANKAGE & ENGINES 0.999837

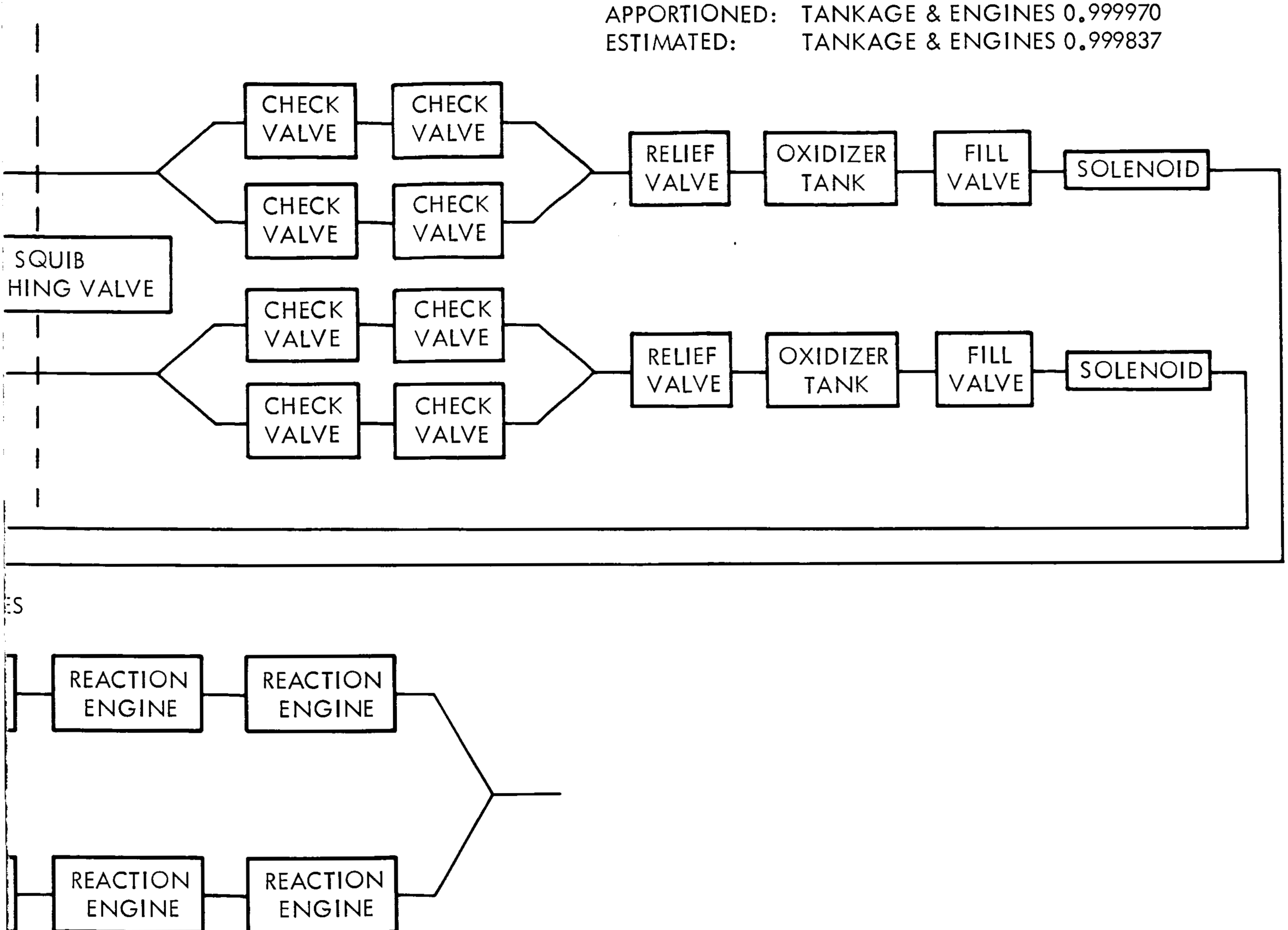
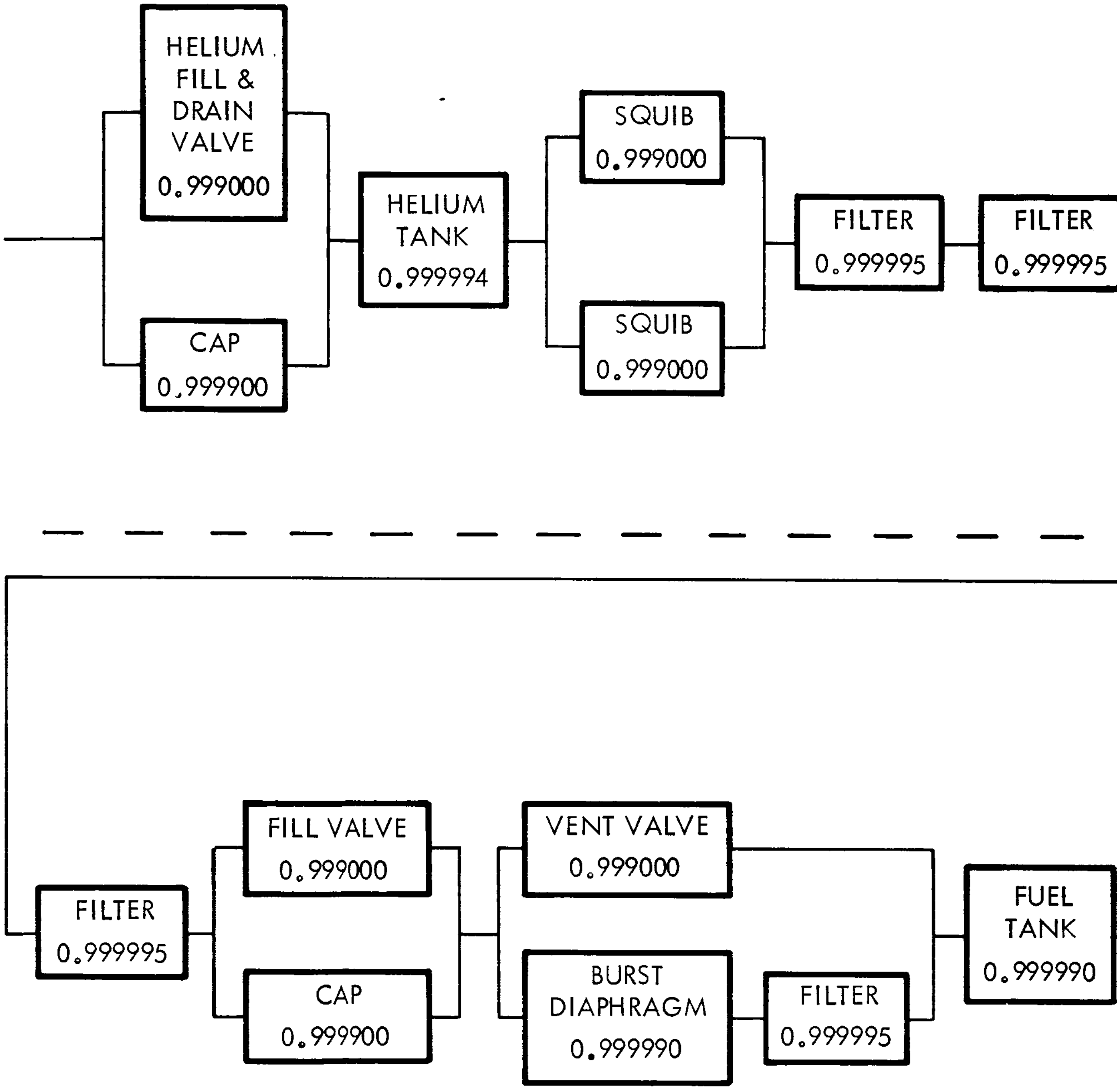


Figure 10. Command Module Reaction Control System Logic

~~CONFIDENTIAL~~

HELIUM SUPPLY
ALLOCATED RELIABILITY: 0.999



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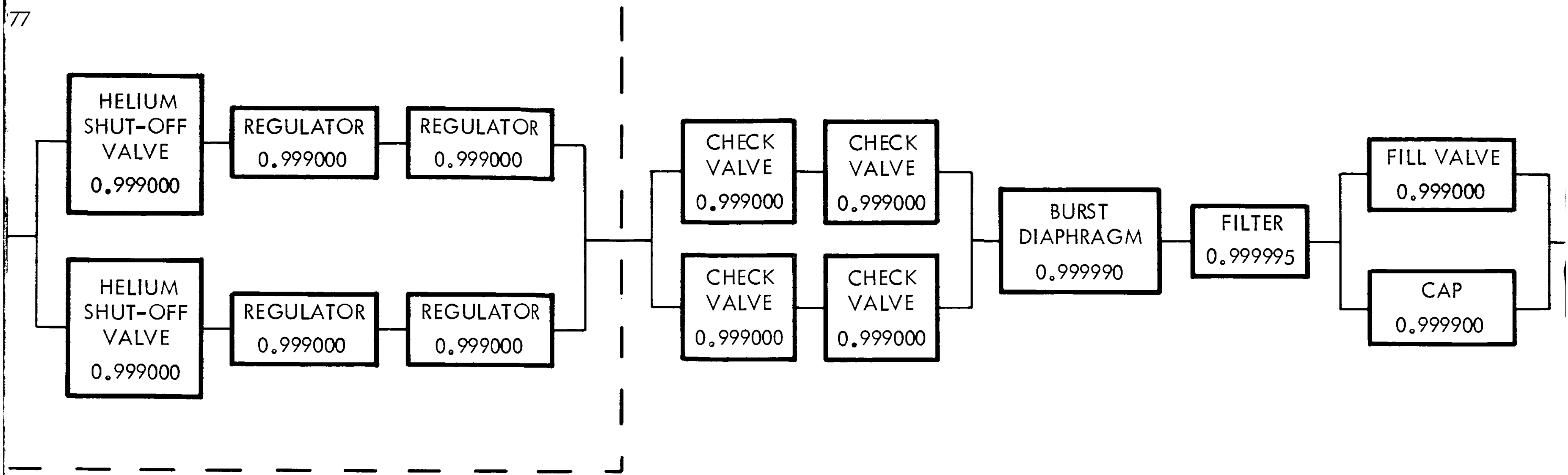

ENGINE ASSEM
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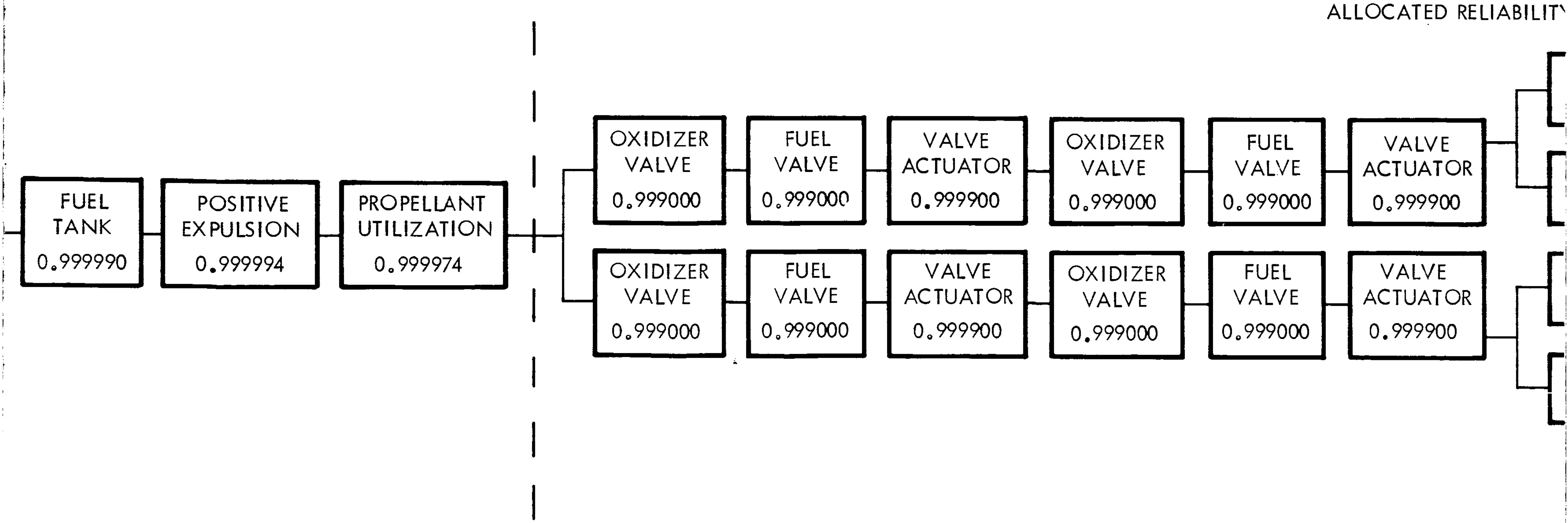


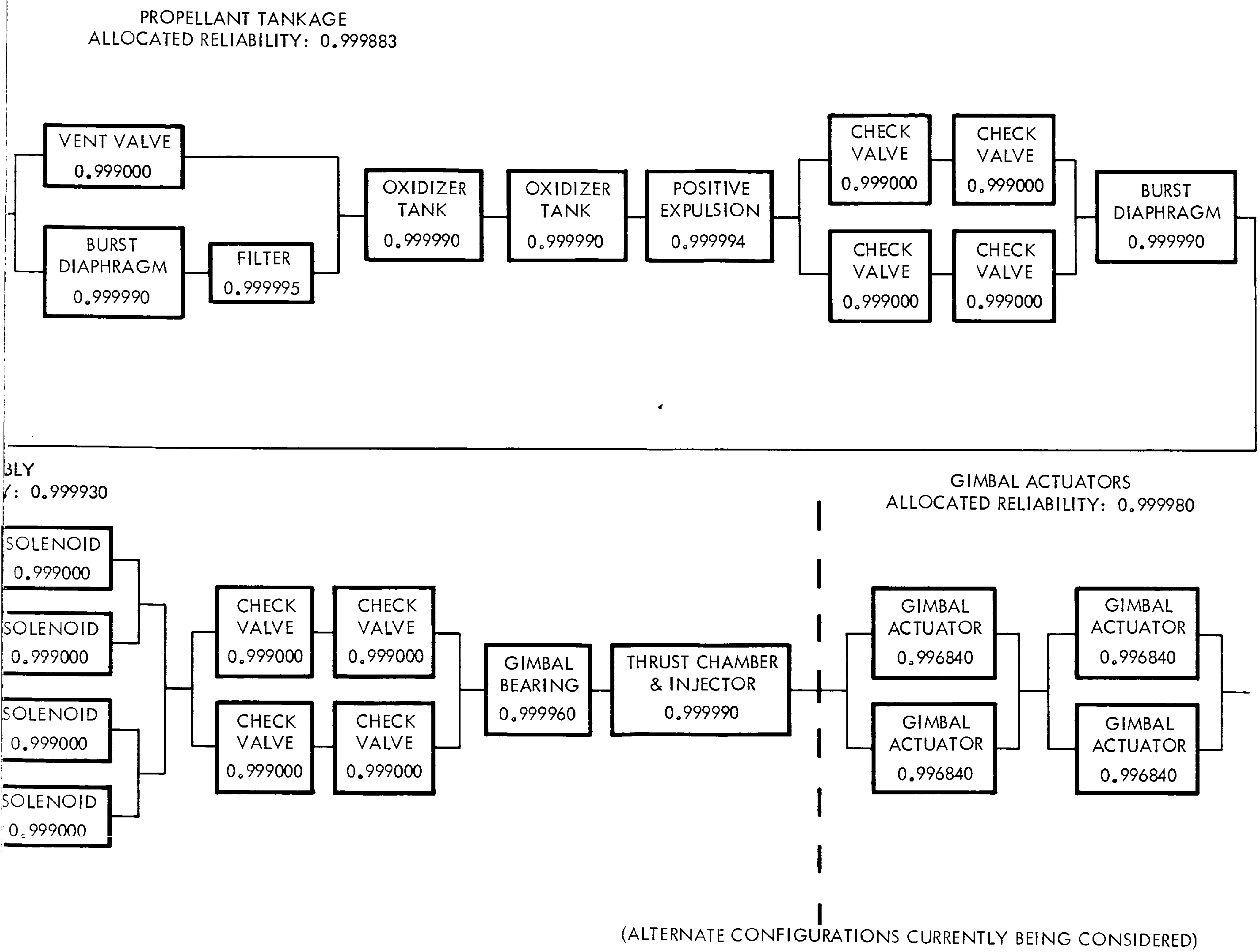
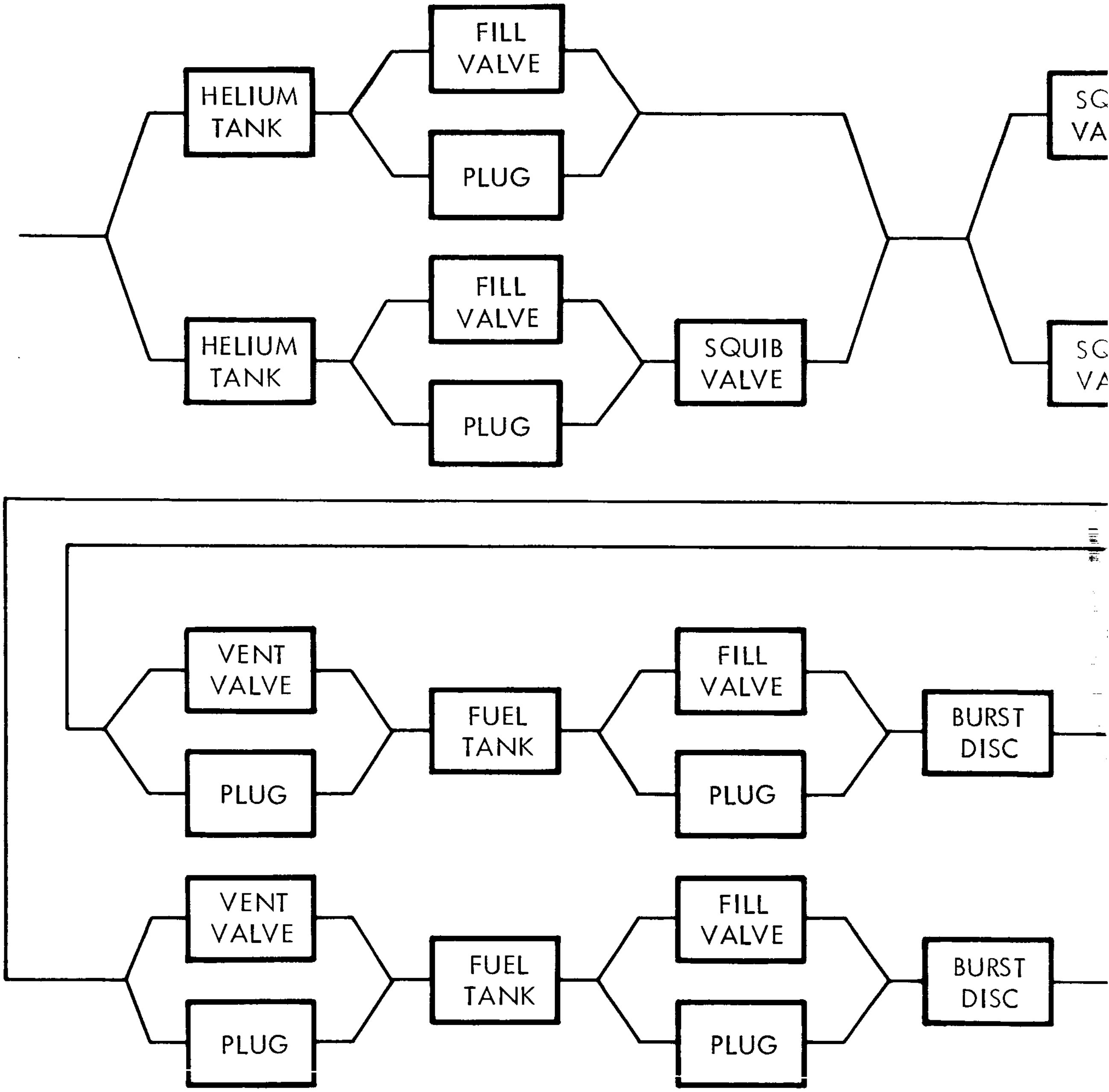


Figure 11. Service Module Propulsion Subsystem Logic

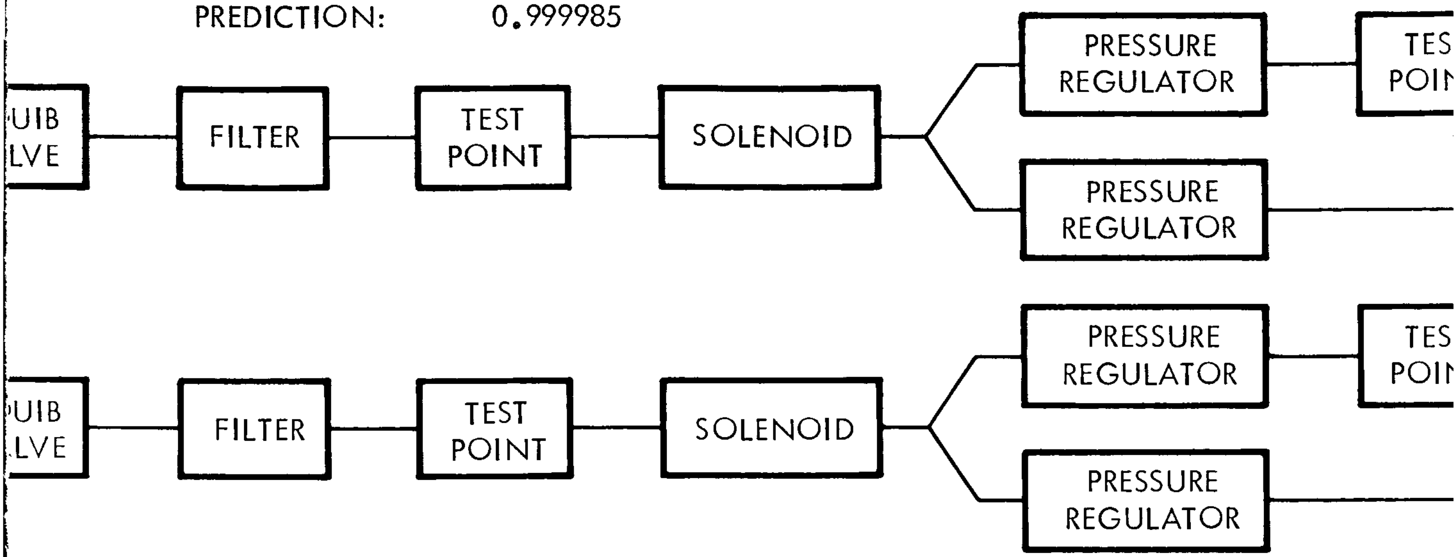


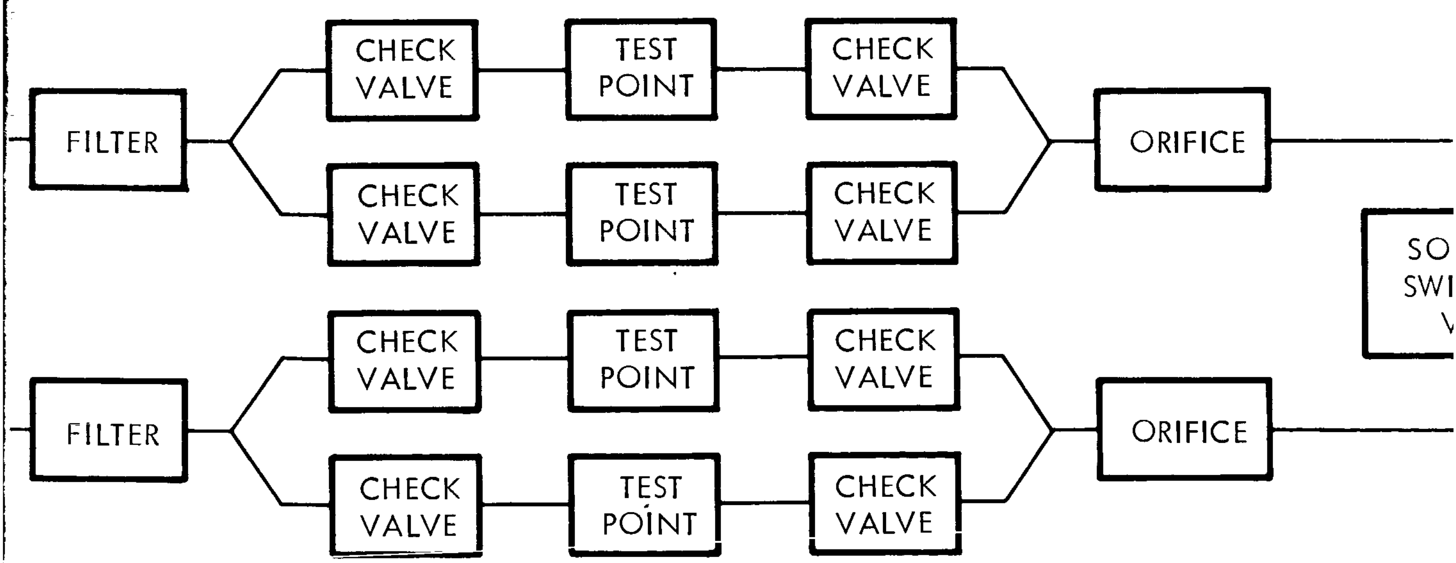
PROPEL

COMBINED TANK
ENGINE CONFIG

HELIUM PRESSURIZATION SYSTEM

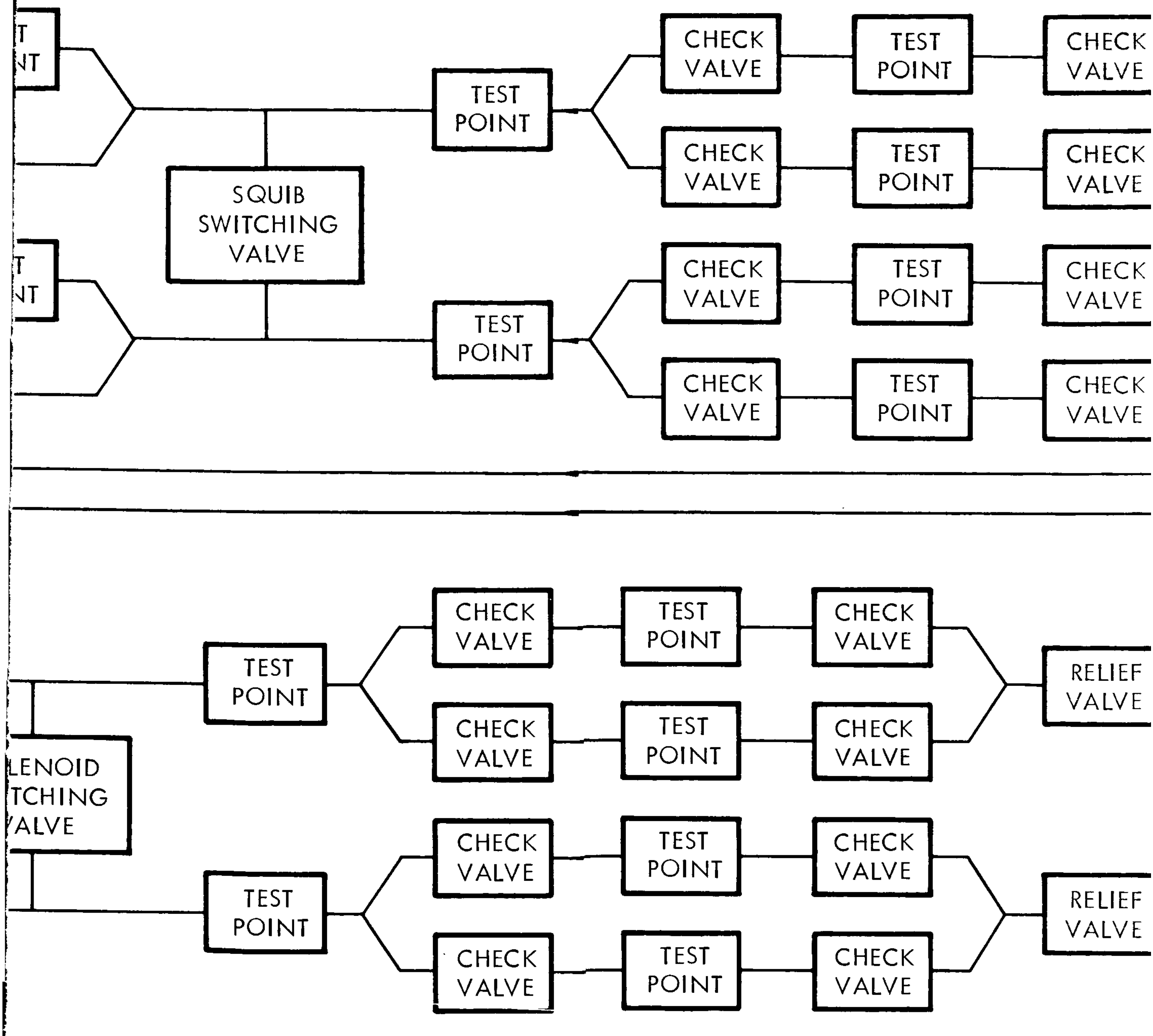
APPORTIONMENT: 0.9995
PREDICTION: 0.999985





.LANT TANKAGE SYSTEM

.AGE APPORTIONMENT: 0.996500
;URATION PREDICTION: 0.957788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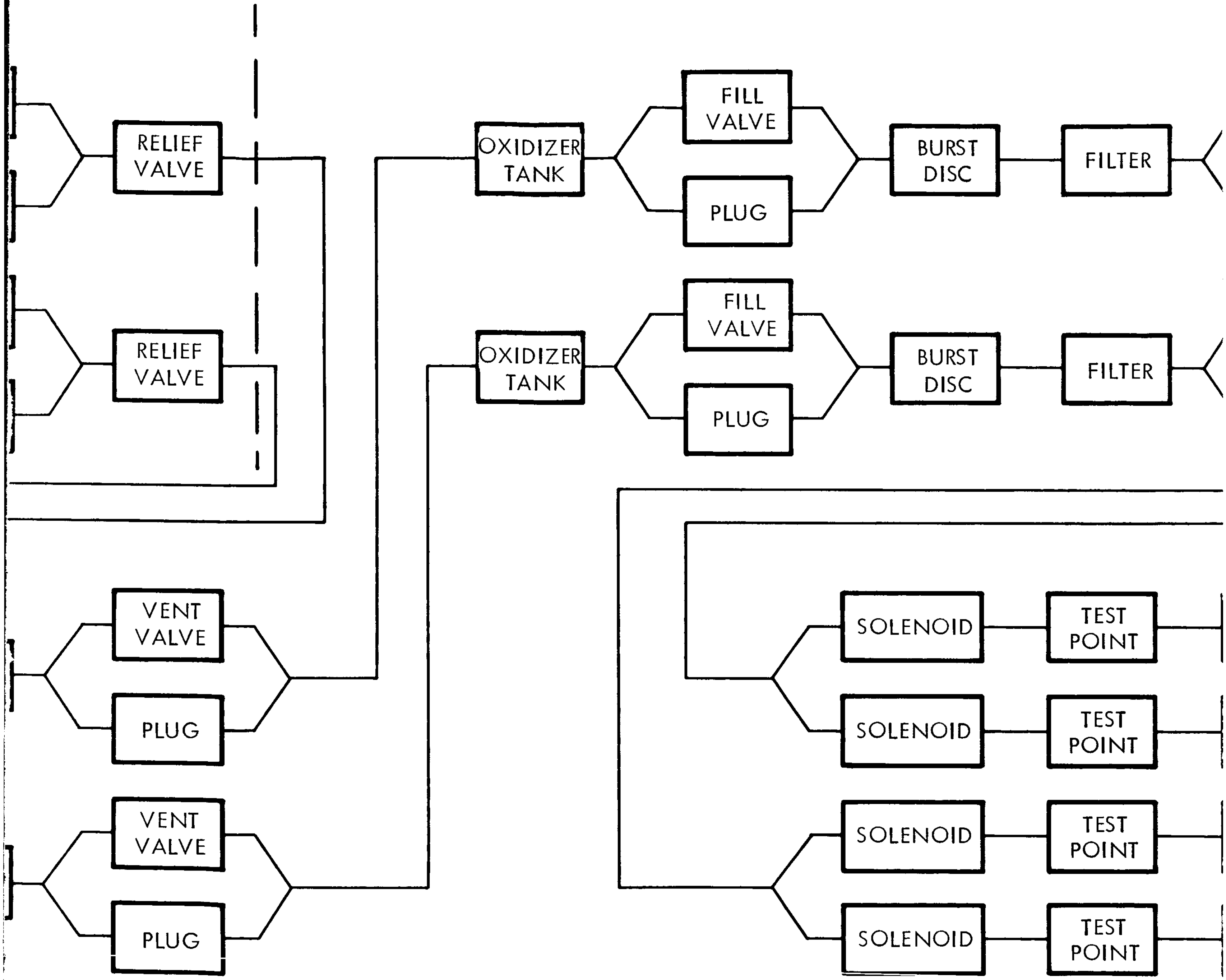

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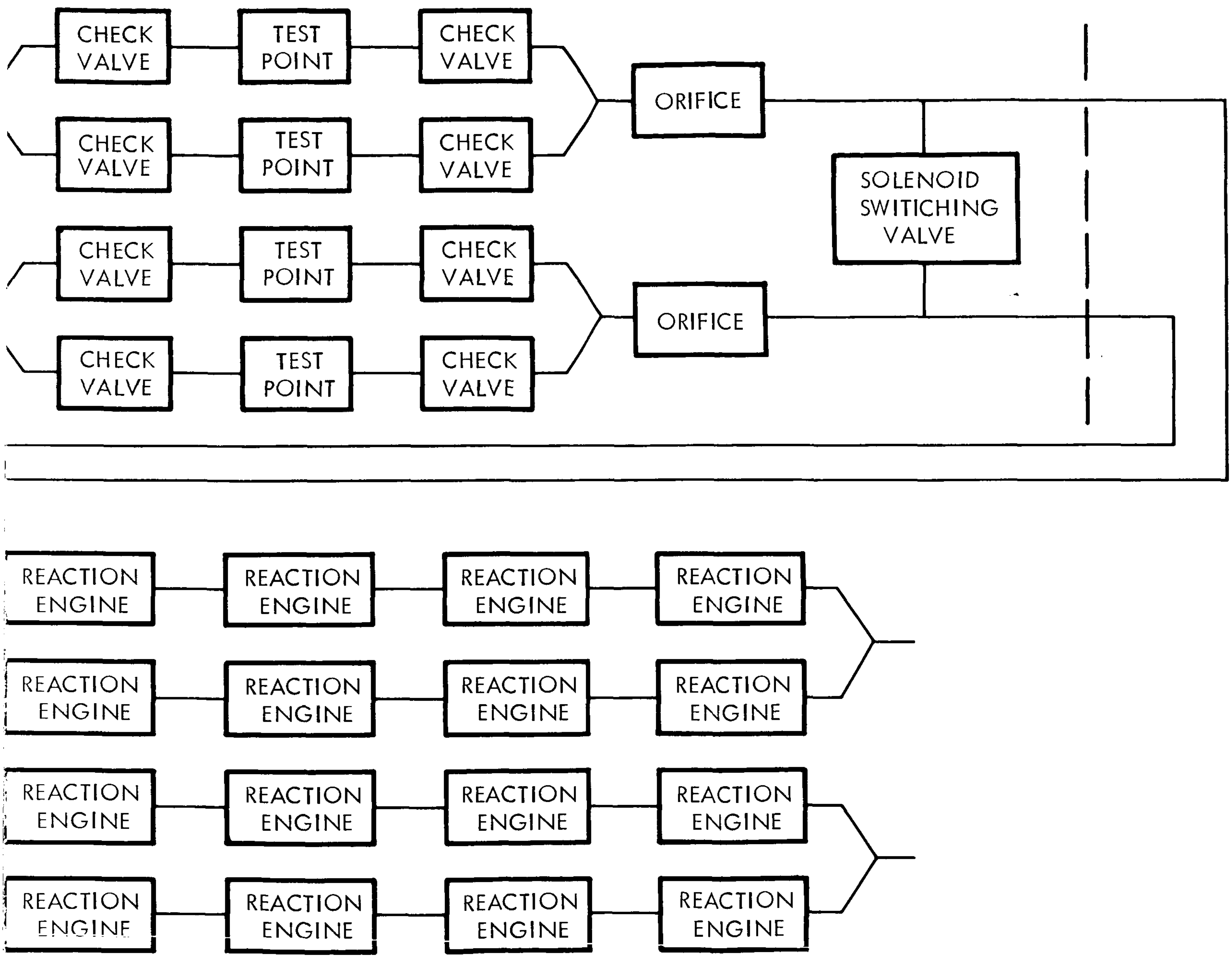

REACTION ENGINES

Figure 12. Service Module Reaction Control Subsystem Reliability Logic

[redacted]

Pressurization and propellant supply will remain in a standby condition ready for intermittant operation for the major portion of the lunar mission. This, coupled with extreme environments, will require some improvement in state-of-the-art reliabilities for most pressurization and tankage components. Significant increases in reliability are required for thrust chambers to meet apportioned reliability objectives delineated in Table 4.

Static Inverter

Two static converter configurations were studied to determine which would provide the highest reliability. The first configuration consists of 13 inverters divided into 5 redundant groups with each group supplying a-c power to a primary subsystem. The alternate configuration consists of 3 redundant inverters supplying all 5 primary subsystems. Any one inverter can maintain system operation. (See Figures 13 and 14.)

For the purpose of analysis, the inverter reliability value of 0.9786, as required in the inverter procurement specification, was employed. The numerical analysis of both systems is as follows:

Configuration No. 1

P_5 = Probability of no failures in the five outputs

$= R_A R_B R_C R_D R_E$

$R_A = 0.99999$

$R_B = 0.99954$

$R_C = 0.97860$

$R_D = 0.99908$

$R_E = 0.99999$

$P_5 = 0.97724$

Configuration No. 2

In this configuration all five outputs are connected to the three redundant main inverters.

[redacted]

Table 4. Service Module Reaction Control Subsystem Apportionment

Item	Subsystem Required	Reliability Apportionment	
		Subassembly* Apportionment	Component Apportionment
Complete subsystem	0.996		
Pressurization		0.9995	
Helium tank			0.995
Fill valve			0.93
Plug			0.9995
Squib valve			0.9980
Filter			0.99975
Test points			0.99975
Solenoid			0.9975
Relief valve			0.999
Regulator			0.95
Check valve			0.999
Tankage and Plumbing		0.9985	
[Oxidizer provisions		[0.99925]	
Fuel provisions (Single leg of redudant provisions)]		[0.99925]	
Vent valve			0.999
Plug			0.9995
Fill valve			0.93
Propellant tank			0.9967
Burst disc			0.9995
Filter			0.99975
Check valves			0.999
Reaction engines		0.9911	
Thrust chamber			0.998

*With redundancy shown in Figure 14.

[redacted]

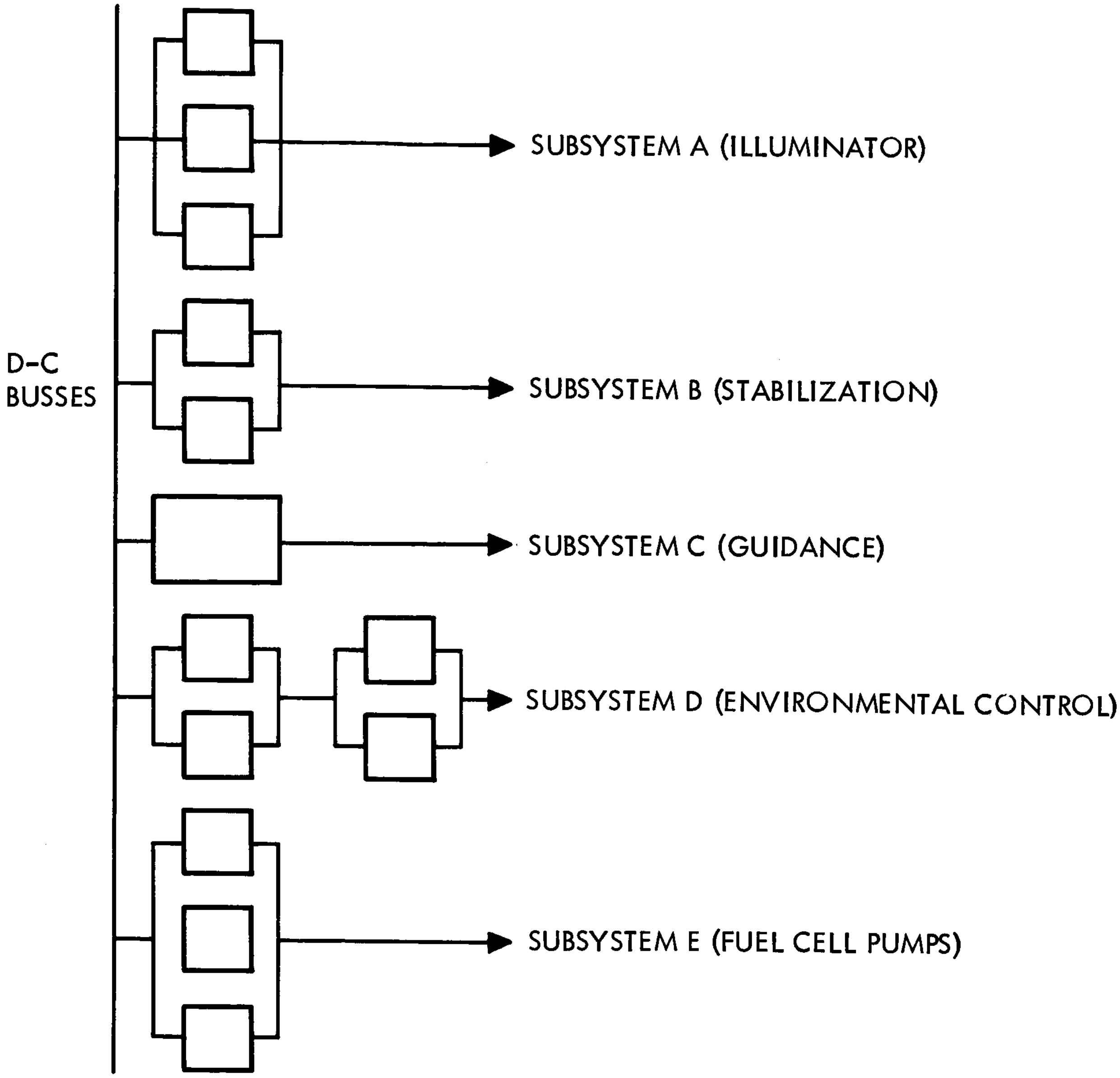

Figure 13. Alternate No. 1 Static Inverter Arrangement

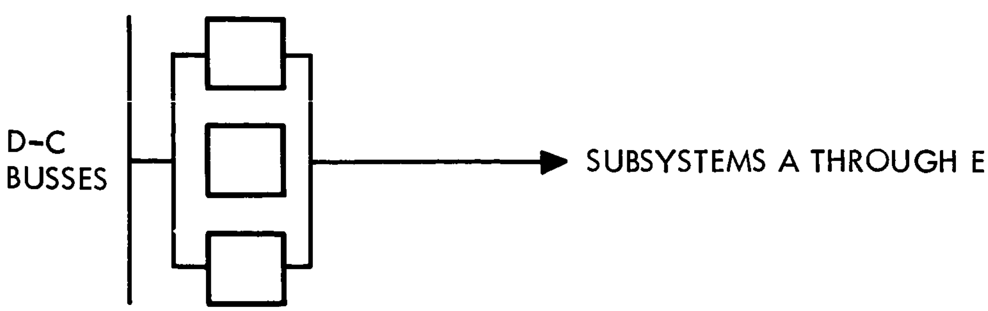

Figure 14. Alternate No. 2 Static Inverter Arrangement

[redacted]

Thus

$$R_3 \text{ (3 redundant inverters)} = 1 - (1 - R_{i3})^3$$

$$= 1 - (0.0214)^3$$

$$= 1 - 0.0000098$$

$$P_5 = R_3 = 0.99999$$

The second configuration is more reliable for a mode of operation that defines any output failure as intolerable. Since all of the primary elements that are supplied by a-c power are considered essential for mission success and crew safety, there appears to be no reliability advantage in supplying each element with individual inverters.

DESIGN ANALYSIS AND REVIEWS

Due to the current preliminary nature of the Apollo program, there has been relatively little detail available for design analysis or reviews. A substantial increase in this activity is anticipated for the next report period, when additional design definitions are formulated and when analyses, initiated in this quarter, are completed and documented. The results of several analyses that have been completed at this stage of development are presented in the subsequent paragraphs.

Earth Landing Impact Attenuation

The results of a qualitative study conducted to investigate various approaches to impact attenuation are presented in their reliability order of preference in Table 5.

Service Module Propulsion Subsystem

Results of the service module propulsion subsystem failure mode analysis conducted during this report period are presented in Table 6.

Reliability Versus Weight Optimization Study

Studies have been initiated to refine spacecraft subsystem reliability requirements and to define optimum system configurations (reliability versus weight). The degree of in-flight testing and maintenance and the required number of on-board spares are being considered. Other factors under consideration are configuration and complexity, degree of redundancy provided, alternate modes of operation, failure prone hardware, failure modes, state-of-the-art and amount of development required, weight of each assembly or end-item package, and criticality of hardware in terms of mission success and crew survival.

[redacted]

[redacted]

Table 5. Earth Landing Impact Attenuation Reliability Considerations and Preference Summary

Considered Characteristics	Vertical & Horizontal Shock Struts	Air Bags With Shock Struts	Top Rockets	Air Bags With Tension Straps	Frangible Honeycomb	Retro-Rockets With Shock Struts	Retro-Rockets With Honeycomb	Retro-Rockets Alone
Preference	1	1	2	3	4	5	6	7
Simplicity	Good	Good	Fair	Good	Fair	Advantage Provides softer landing if all retro-rockets operate Some redundancy	Advantage Some measure of redundancy is provided	Poor
Reliability margin	Good	Good	Fair	Fair	Poor			None
Instrumentation (crew display)	Minimum	Minimum	Maximum	Minimum	Minimum			Maximum
Interaction with other systems	None	None	Electrical power required	None	None	Disadvantage Any single rocket failure could cause loss of the crew	Disadvantage Encompasses detrimental aspects of both systems	Electrical power required
Allowable failures	Allows multiple shock strut failures	Tolerant 2/7 bags 4/8 struts	Possible to lose one rocket	Allows 2/7 bag failures	None			None
Mechanization required	Minimum	Minimum	Nominal	Minimum	Nominal			Maximum
Crew requirements	None	None	Requires crew override	None	None			Requires crew override
Probability of exceeding crew emergency limits	Remote	Remote	Low	Tumbling could cause crew incapacitation	Capsule must land on honeycomb area			Any rocket failure could cause loss of the crew

[redacted]

[redacted]

Table 6. Service Module Propulsion Subsystem Failure Mode Analysis (Lunar Launch)

Component	Failure Mode	Probable Cause	Failure Effect Upon		Operating Time	Remarks
			Mission Success	Crew Survival		
Quad check valves	One fails to check reverse flow	Seal breakdown	None	None	500 seconds	
	Two fail in alternate legs		None	None		
	Two fail in same leg		None	None		Helium back pressure applied directly to regulator.
Oxidizer Fuel quad check valves	One fails to check reverse flow		None	None	500 seconds	
	Two fail in alternate legs	Seal breakdown	None	None		Possible corrosion of up-stream components.
	Two fail in same leg		Loss	Loss		Oxider and fuel fumes intermit causing explosive atmosphere
Oxidizer and fuel burst disc (inlet)	Does not rupture Faulty material		Loss	Loss	1 cycle	Sufficient safety margin should preclude this mode.
	Ruptures prematurely	Shock or vibration	None	None		
Oxidizer and fuel filter (inlet)	Clogs	Debris or moisture forming ice	Loss	Loss	500 seconds	
Vent valve (oxidizer and fuel)	Opens during flight	Vibration and shock	None	None	None	Plug assures no leakage.
	Leakage thru stem	Breakdown of seal	Effects	Unknown		Could cause eventual depletion of pressurant.
Burst disc relief (oxidizer and fuel)	Does not rupture when required	Faulty burst material	Loss	Loss	1 cycle	Possible tank rupture.
	Ruptures pre-maturely	Shock or vibration	None	None		Relief valve precludes loss of helium.
Relief valve (oxidizer and fuel)	Opens pre-maturely	Shock or vibration	None	None	300 seconds (maximum)	Burst disc prevents loss of helium. Requires previous malfunction before relief use required.
	Does not open when required	Corrosion causing sticking	Loss	Loss		
Propellent tanks	Rupture	Meteroid damage vibration	Loss	Loss	14 days	Sufficient overdesign should preclude leakage or rupture.
	Leakage	Shock-lunar touchdown				
Fill valve (oxidizer and fuel)	Leakage during flight	Shock, vibration breakdown of seal	None	None	Only during tanking	Plug acts as back-up.
Burst disc (oxidizer and fuel outlet)	Does not rupture	Faulty material	Loss	Loss	One-shot device	High tank pressure should preclude this mode.
	Ruptures pre-maturely	Shock or vibration	None	None		Possible contamination of downstream components.
Filter (oxidizer and fuel tank outlet)	Clogs	Propellant debris	Loss	Loss	500 seconds	Considerable care must be taken during filling.
		Moisture in line forming ice				

[redacted]

[redacted]

Table 6. Service Module Propulsion Subsystem Failure Mode Analysis (Lunar Launch) (Cont)

Component	Failure Mode	Probable Cause	Failure Effect Upon		Operating Time	Remarks
			Mission Success	Crew Survival		
Helium tank	Rupture leakage	Meteroid damage, Vibration, Shock, lunar Touchdown	Loss	Loss	14 days	Sufficient over-design should preclude leakage or rupture.
Fill valve	Leakage	Breakdown of valve steam seal	None	None	Does not apply	Plug provided as backup-valve checked off to lift-off.
Dual squib valves (normally closed)	One fails to open	Igniter or connector breakdown	None	None	1 shot device	Primary consideration is to eliminate or protect against stray electrical signals.
	One or both open prematurely	Inadvertant electrical signal	Effects Unknown			
	Both fail to open	Loss of electrical signal	Loss	Loss		
Filter	One clogs	Moisture freezes debris from squib	None	None	500 seconds	Utmost care to utilize clean opening squip valves.
	Both clog		Loss	Loss		
Solenoid valve (normally open)	Fails closed	Inadvertant electrical energization	None	None	1 cycle	Alternate line used.
	Does not close when required	Loss of current	None	None		Alternate solenoid acts as backup
Filter	Clogs	Low probability all debris should be removed.	None	None	500 seconds	Alternate line used.
Pressure regulator	Indicates high pressure when none exists	Malfunction of pressure indicator	None	None	500 seconds	Solenoid used for isolation.
	Indicates low pressure when none exists		None	None		Pressure indicator downstream indicates pressure for correlation. Any surges removed by relief valve.
Solenoid valve (normally open)	Closes inadvertently	Stray electrical signal	None	None	1 cycle	
	Does not close when required	Electrical malfunction solenoid breakdown	None	None		Requires regulator and upper solenoid malfunction before operation is required.
Solenoid valve (normally closed)	Does not open on command	Electrical malfunction	None	None	1 cycle	Alternate solenoid used.
	Both do not open on command	Solenoid breakdown	Loss	Loss		Requires previous malfunction.
	Open prematurely	Stray electrical signal	None	None		Pressure regulator maintains flow.
	Both close during operation	Loss of electrical signal	Loss	Loss		Requires previous malfunction.
Filter	Clogs	Debris Moisture that has frozen in filter	Loss	Loss	250 seconds	Requires loss of alternate filter.
Pressure regulator	Indicates high pressure when none exists	Malfunction of pressure indicator	Effects Unknown		250 seconds	Under pressurization of fuel tanks.
	Indicates low pressure when none exists		None	None		Relief valve protects against over-pressurization although gradual depletion of helium may occur.

[redacted]

[redacted]

Table 6. Service Module Propulsion Subsystem Failure Mode Analysis (Lunar Launch) (Cont)

Component	Failure Mode	Probable Cause	Failure Effect Upon: Mission Success	Failure Effect Upon: Crew Survival	Operating Time	Remarks
Quad check valves (oxidizer and fuel outlet)	One fails to check reverse flow	Seal breakdown	None	None	500 seconds	
	Two fail in alternate legs	Corrosion by propellants causing sticking	None	None		
	Two fail in same leg		Effects	Unknown		Improper engine operation during midcourse correlation.
Primary propellant utilization valve	Valve drives hard over closed		None	None	500 seconds	
		Malfunction of computer or logic network	None	None		Normally open solenoid closes propellant utilization control maintained by redundant prepellant utilization valve.
	Loss of power	Electrical malfunction	None	None		
Normally open solenoid	Inadvertantly closes	Stray electrical signal	None	None	1 cycle	
	Does not close when required	Loss of energizing signal	None	None		Assumes alternate propellant utilization valve will maintain control.
Secondary propellant utilization valve	Drives hard over closed	Malfunction of computer or logic network	Loss	Loss	250 seconds	Both propellant utilization valves must be hard over closed. Engine burns oxidizer rich.
	Drives hard over open		None	None		
	Loss of power	Electrical malfunction	None	None		Valve should return to null position.
Engine propellant valves	Two alternate sets do not open	Electrical failure corrosion causes sticking	Loss	Loss	500 seconds	
	Two alternate sets do not close		Loss	Loss		
Injector	Plugging	Debris in line	Loss	Loss	500 seconds	Low probability of occurrence.
Thrust chamber	Burn through	Performance vibration	Loss	Loss	500 seconds	Requires injector plugging to cause performance variation.

[redacted]

MATERIALS, PARTS, AND COMPONENTS

The investigations initiated and the acquisitions made during this report period are outlined in the following paragraphs.

Transducer Study

Transducer application and reliability data have been received from 22 leading transducer manufacturers. Two reliability reports have also been received from Borg Warner Controls and Edcliff Instruments.

Elapsed Time Meters

A study to assess relative merits of various elapsed time meters is being conducted. Representatives of 20 manufacturers have been contacted for information. Presentations of these companies will be employed to determine time-significant information on mission-essential Apollo equipment. Catalogs and drawings of clock and digital elapsed time meters have been received. A miniaturized version of the digital unit is the most promising. Engineering and reliability data to support this study will be furnished by the suppliers and will be transmitted to appropriate S&ID and supplier design personnel.

Relay Versus Solid-State Devices

To obtain additional reliability data to assist in reaching Apollo design decisions on the use of relays versus solid-state devices, eight major relay and solid-state device manufacturers and other NAA divisions have been contacted. Suppliers will submit reliability test reports, quality control test reports, design application information, MTBF and failure rate data. A preliminary report will be issued when this information is received.

Connector Study

A list of connector classes and styles to fulfill major GSE requirements is in process, and representatives from six major connector manufacturers and other NAA divisions have been contacted. It is planned to group these components by class, type (per Mil-Spec.), supplier, and configuration. When reliability information has been received, it will be added to this listing. Particular emphasis has been placed on the need of available reliability data beyond the environmental limits of Mil-C-26500.

[redacted]

Vessel Burst Study

A study to obtain predesign information on titanium pressure vessels has been conducted in the following source areas: (1) IDEP, (2) field data from aircraft and missile industries using titanium vessels, (3) supplier contacts, and (4) other NAA divisions.

Helium, Nitrogen Tetroxide, Hydrazine Pressure System Components

Failure rate data is being sought on components to be used in pressurization and propellant applications. Information that could provide reliability assessments on these components is being requested from the same sources that will supply the vessel burst study data.

QUALIFICATION-RELIABILITY TEST PROGRAM

The Apollo Qualification-Reliability Test Plan, SID 62-204, was released 28 February 1962. A review at NASA, MSC, Houston on 8 and 9 March resulted in the following decisions:

1. MSC tentatively concurred with the NAA general approach to testing.

2. Individual test procedures would be prepared by NAA to provide greater detail than presented in the test plan.

3. Several changes and additions were requested and agreed on.

4. Additional discussions on the statistical treatment of test data were scheduled for the week of 19 March 1962 at NAA.

Meetings were held on 21 and 22 March to discuss the statistical aspects of the test plan. In order to be certain that the proposed plan was the best available approach to qualification and reliability demonstration, it was jointly agreed that a consultant should be engaged for a one to two week study. Further discussions on the selection of a qualified consultant are to be held in the next report period. Revisions to the test plan are being incorporated for transmittal to MSC by 30 April 1962.

Model test plans are being constructed and documented for various categories of Apollo hardware, such as parts, components, subsystems, and systems. These model plans, in conjunction with the following information, will define the number of items required for qualification-reliability testing, complexity, failure modes, current qualification status, cost, number of critical environments, reliability requirements, and confidence objectives.

[redacted]

[redacted]

Copies of the model plans will be transmitted to all major subcontractors to assure uniformity in approach and continuity of data from supplier through NAA-conducted tests. Other test accomplishments for this period are reported under Associate and Subcontractor Activities in this document.

DATA SYSTEM

Data Support

Studies were conducted to define the data collection and processing requirements necessary to support failure analysis and reliability testing on the Apollo program. Deficiency and failure data report forms are being received, and supporting procedures are currently being developed and documented to assure conformance to NASA requirements. A discrepancy study code (DSC) has been developed and is being implemented. The purpose of this code is to rapidly identify repetitive failures and dificiencies and to assure corrective action by responsible personnel.

Feedback (output) reports and processing procedures necessary to satisfy the basic requirements of an acceptable reliability program are being completed in order to expeditiously circulate information when the failure report program goes into effect.

Statistical Support

Parameters were defined for producing statistical summaries in matrix form from a rapid reporting system. Statistically designed experiments are being devised for use in measuring the effects of environments encountered from prelaunch to reentry for all Apollo systems, subsystems, and components. Statistical support is currently in progress in establishing the reliability requirements and criteria for hardware purchased from S&ID suppliers.

DOCUMENTATION

Reliability Program Plan

The Reliability Program Plan (SID 62-203) is being revised as a result of discussions with NASA personnel on 8 to 9 February. No major reorientation of the program was requested. Significant items requested by NASA were as follows:

1. The report should contain schedule milestone charts.

2. Organizational relationships and authority of Apollo and central function reliability engineering should be amplified.

3. Time limitations for failure reporting and analysis should be defined.

4. Engineering changes and change control should be expanded.

5. Employment and documentation of mission phase apportionments should be explained.

Qualification-Reliability Test Plan

As a result of the meeting with NASA personnel on 8 to 9 February, the Qualification-Reliability Test Plan is being revised. This document is to be transmitted to NASA by 30 April 1962.

Environmental Criteria Notebook

The objective of the Environmental Criteria Notebook is to provide a central document for recording the environmental levels to which the Apollo spacecraft and ground support subsystems andequipments will be exposed. Environmental criteria are accumulated by phase, beginning with initial Apollo assembly and checkout through recovery from a lunar mission. Concurrent with the determination of expected mission environments, individual analyses are being performed for each subsystem to establish the necessary design and test levels. Revisions will be made as required.

Reliability Support To Other Documents

During this report period, Reliability Engineering supported the preparation and release of numerous documents. This activity consisted of reviews and contributions in the form of reliability program requirements, numerical requirements, environmental criteria, and test planning and methods. Table 7 delineates NAA work statements containing reliability contributions originated in this quarter.

Table 8 lists those procurement specifications and other documents that have reliability contributions and that have been reviewed by Reliability Engineering before release.

[redacted]

Table 7. Reliability Contributions to Work Statements
(January Through March 1962)

Document Number	Subsystem	Subcontractor	Date Submitted (1962)
SID 62-10	Environmental control	AiResearch	Jan 10
SID 62-11	Stabilization & control	Minneapolis - Honeywell	Jan 10
SID 62-12	Telecommunications	Collins Radio	Jan 10
SID 62-14	Fuel Cells	Pratt & Whitney	Feb 12
SID 62-16	Earth landing impact attenuation	(North American Aviation)	Jan 1
SID 62-17	Earth landing recovery aids	Radioplane	Jan 5
SID 62-18	Escape tower jettison motor	Thiokol	Feb 12
SID 62-19	Service module propulsion motor	Aerojet	Feb 28

[redacted]

[redacted]

Table 8. Reliability Contributions to Apollo Specifications (January Through March 1962)

Number	Title	Date Submitted (1962)
MC481-0001	Antenna System, R & D Telemetry	Mar 9
MC481-0002	Antenna System, Recovery	Mar 16
MC481-0003	R & D Beacon Antenna System	Mar 21
IDWA 5508 (LA)	Radome Specification, Antenna	Mar 28
MC286-003	Helium System Filter	Mar 15
MC284-001	Solenoid Valve	Mar 15
MC282-000-3	Helium Tank (Command Module)	Mar 15
MC495-0001	Inverter	Mar 27
MC461-0001	Post Landing Battery	Mar 29
MC461-0003	Reentry Battery	Mar 29
MC901-0005	Super-Critical Gas Storage System	Mar 20
MC464-0002	Launch Escape Motor	Mar 9
SID 62-50	Apollo General GSE Specification	Feb 10
SID 62-51	Spacecraft Performance Specification	Jan 17
SID 62-65	Design Criteria Specification	Feb 16
SID 62-80	Spacecraft Mission Propulsion Subsystem Specification	Feb 19
SID 62-82	Spacecraft Environmental Control Subsystem Specification	Feb 5
SID 62-84	Spacecraft Navigation and Guidance Subsystem Specification	Feb 28
SID 62-83	Spacecraft Electrical Power Subsystem Specification	Jan 25
SID 62-85	Spacecraft Stabilization and Control Subsystem Specification	Jan 10
SID 62-86	Spacecraft Telecommunications Subsystem Specification	Mar 5
SID 62-88	Spacecraft Launch Escape Subsystem Specification	Mar 15
SID 62-89	Spacecraft Parawing and Recovery Subsystem Specification	Mar 15
SID 62-96	Preliminary Apollo Support Plan	Mar 15
SID 62-109	Test Plan Research and Development for Project Apollo Spacecraft	Jan 15
SID 62-192	Electro-Magnetic Interference Specification for Apollo Spacecraft	Mar 22
SID 62-239	General Requirements for Preparation for Delivery of Apollo GSE	Mar 1
SID 62-240	General Requirements for Preparation for Delivery of Apollo Airborne Equipment	Mar 16

[redacted]

Table 9. Procurement Specification Inputs This Quarter

Number	Title	Date Submitted (1962)
MC481-0001	Antenna System, R & D Telemetry	Mar 9
MC481-0002	Antenna System Recovery	Mar 16
MC481-0003	R & D Beacon Antenna System	Mar 21
MC286-0003	Helium System Filter	Mar 15
IDWA 5508 (LA)	Radome Specification, Antenna Spec	Mar 28
MC284-001	Solenoid Valve	Mar 15
MC282-000-3	Helium Tank (Command Module)	Mar 15
MC495-0001	Inverter	Mar 27
MC461-0003	Reentry Battery	Mar 29
MC461-0001	Post Landing Battery	Mar 29
MC901-0005	Super-Critical Gas Storage System	Mar 20
MC464-0015	Fuel Cell	Mar 12
MC901-0002	Launch Escape Motor	Mar 9
SID 62-50	General GSE Apollo Specification	Feb 10
SID 62-51	Spacecraft Performance Specification	Jan 17
SID 62-65	Design Criteria Specification	Feb 16
SID 62-80	Spacecraft Mission Propulsion Subsystem Specification	Feb 19
SID 62-82	Spacecraft Environmental Control Subsystem Specification	Feb 5
SID 62-83	Spacecraft Electrical Power Subsystem Specification	Jan 25
SID 62-84	Spacecraft Navigation and Guidance Subsystem Specification	Feb 28
SID 62-85	Spacecraft System Stabilization and Control Subsystem Specification	Jan 10
SID 62-86	Spacecraft Telecommunications Subsystem Specification	Mar 5
SID 62-88	Spacecraft Launch Escape System Subsystem Specification	Mar 15
SID 62-89	Spacecraft Parawing and Recovery System Specification Subsystem	Mar 15
SID 62-192	Electra-Magnetic Interference Specifications for Apollo Spacecraft	Mar 22
SID 62-239	General Requirements for Preparation for Delivery of Apollo GSE	Mar 1
SID 62-240	General Requirements for Preparation for Delivery of Apollo Airborne Equipment	Mar 16
MC284-0013	Valve Solenoid Actuated, Nitrogen Tetroxide Feed Control	Apr 13
MC282-0005	Pressure Vessel, Helium (48 inch Nominal ID)	Apr 11
MC282-0002	Pressure Vessel, Helium (10 inch Nominal Diameter)	Apr 11
MC282-0007	Tank UDMH/Hydrazine - Positive Expulsion (cylindrical)	Apr 16
MC282-0006	Tank - Nitrogen Tetroxide - Positive Expulsion (cylindrical)	Apr 16
MC282-0008	Tank, UDMH/Hydrazine - Positive Expulsion (16-1/4 Nominal I. D.)	Apr 16

MOTIVATION AND TRAINING

Initial plans for an Apollo Reliability Training Program are being formulated. Early subjects to be covered are (1) Minuteman standards and application suitability data, (2) design analysis techniques and associated machine programs, (3) statistically designed tests, and (4) the Apollo reliability program plan. Nine additional subjects are being considered.

A briefing was presented on 15 March to introduce program and engineering management to the Minuteman high-reliability electronics approach, to its possible application to Apollo, and to the ramifications of this implementation on the Apollo. As a follow-on effort, some of the significant problem areas being studied as parts availability, documentation scope, procurement procedures, supplier and in-house controls, receiving-inspection test equipment, requirements for controlled environmental storage, and data handling requirements and facilities. It is anticipated that joint action will be required from program management, purchasing, avionics and GSE design, reliability engineering, quality control, and standards before a practical implementation and procurement plan can be formulated.

Forty copies of the Minuteman Standards Handbook has been distributed to design, reliability, and subcontractor personnel. An introduction with pertinent comments on employment of the standards in Apollo preliminary design was prepared to supplement the handbook.

A reliability briefing has been prepared, and is to be presented on 5 April 1962 to NAA, Tulsa personnel who will be engaged in Apollo work. Material to be covered includes divisional and program reliability policy and organization and the Apollo Reliability Plan. The briefing will be followed by a showing of the motivational film "Lock On."

An Interdivisional Work Authorization (IDWA) has been issued to Autonetics to provide a course and instructors on the subject of "Machine Program Circuit Analysis Techniques." The course will cover worst-case, VINIL, moment methods, parameter variation, and Monte Carlo Analysis techniques; and it will be open to Apollo design and reliability engineers.

ASSOCIATE AND SUBCONTRACTOR ACTIVITIES

S&ID Reliability personnel have participated as members of various pre-award survey teams. To assure uniformity and coverage of significant reliability considerations, a pre-award survey handbook was prepared. This handbook is in the form of a detailed checklist and forms the basis for evaluation of management and technical capabilities, personnel, procedures, facilities, etc. Table 10 is a list of the supplier surveys conducted during this quarter.

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Table 10. Pre-Award Surveys (January Through March 1962)

Launch Escape/Tower Jettison Motor	Lockheed Propulsion Co., Redlands Aerojet-General Corp., Solid Rocket, Sacramento, California United Technology Corp., Sunnyvale Rocket Power, Inc., Mesa, Arizona Thiokol Chemical Corp. Elkton, Maryland
Command Module Heat Shield Ablative Panels	AVCO R & D Facility Wilmington, Massachusetts General Electric Facility Philadelphia, Pennsylvania Cincinnati Testing Laboratory Cincinnati, Ohio Emerson Electric, Avionics Facility St. Louis, Missouri Chance Vought Corp. Dallas, Texas
Fuel Cell	Ionics Corp. Boston, Massachusetts Allis Chalmers Milwaukee, Wisconsin Pratt & Whitney Aircraft East Hartford, Connecticut
Service Module Propulsion Engine	Thiokol Chemical Corp., Reaction Motors Division Denville, New Jersey
Attitude and Reaction Control Motors	Marquardt Corp. Van Nuys, California

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Table 10. Pre-Award Surveys (January Through March 1962) (Cont)

Reentry and Recovery Batteries
Delco Remy Division, GMC Anderson, Indiana
The Eagle-Picher Co., Chem.-Metals Division Joplin, Missouri
Electrical Storage Battery Co., Missile Division Raleigh, North Carolina
Gulton Industries, Alkaline Battery Division Metuchen, New Jersey
Yardney Electric Corp. New York 13, New York
Power Sources Division, Telecomputing Corp. Denver 7, Colorado
Super-Critical Gas Storage System
Stratos Division, Fairchild Stratos Corp. Manhattan Beach, California
Airite Products, Inc. Division, Electrade Corp. Los Angeles, California
Menasco Mfg. Co., Burbank, California
Hamilton Std. Division, United Aircraft Windsor Locks, Connecticut
Linde Co., Cryogenics Prod. Dept. Town of Tonawanda, New York
Firewell Co. Buffalo 25, New York
Pioneer Central Division Bendix Corp. Davenport, Iowa
Beech Aircraft Corp. Witchita, Kansas
Beech Aircraft Corp. Boulder, Colorado
Parker Aircraft Los Angeles 45, California

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Table 11. defines various subcontractor documents which were reviewed by Reliability Engineering during this report period.

Table 11. Subcontractor Reports Reviewed by Reliability Engineering

Report	Title	Company
SS-1003-R	Reliability Program Plan for the Apollo Environmental Control Subsystem (ECS (ECS)	AiResearch
AR113-1	Reliability Tests for the Apollo Telecommunications subsystem	Collins
SS-1015-R	QC Instrumentation Measuring and Test Equipment ECS	AiResearch
RED-18004	Preliminary Test Plan for Apollo Stabilization and Control Subsystem	Minneapolis-Honeywell
RSS-1013R	ECS Progress Report No. 1	AiResearch
SS-1014R	Design Criteria Specification ECS	AiResearch
AR-108-1	Telecommunications Reliability Program Plan	Collins
RED-18011	Stabilization and Control Subsystem Reliability Program Plan	Minneapolis-Honeywell
2519	Design Criteria Specification Earth Landing Subsystem	Radioplane
SS1012R	End Item Test Plan ECS	AiResearch
18004A	Test Plan	Minneapolis-Honeywell
2523	Test Plan	Radioplane
SS1004R	Reliability Test Plan	AiResearch
2522	Facilities Plan	Radioplane
2506	Apollo Earth Landing Subsystem Program Plan	Radioplane
RED-18015	Qualification-Reliability Test Program for the Apollo Stabilization and Control System	Minneapolis-Honeywell
AR118-1	Quality Control Plan for the Telecommunications System	Collins
PTM-424	Review of Application Study-Drogue Stabilization Parachute	Radioplane

The following represent significant subcontractor accomplishments as determined to date.

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AiResearch Manufacturing Division

The AiResearch Reliability Program Plan for the environmental control sub-system was reviewed. The document did not contain adequate information to assure compliance with the requirements of MIL-R-27542 and NCP 200-2, and a more detailed plan was requested.

Collins Radio Company

The Collins telecommunications subsystem Reliability Program Plan has been reviewed by NAA/S&ID. This plan has been rejected because of insufficient detail to grant approval.

Collins' Qualification-Reliability Test Plan was reviewed and found to have inadequately described the planned tests or the methods in which they were to be employed. An outline of the material presented in NAA/S&ID's Qualification-Reliability Test Plan was submitted to Collins in order to assist in the preparation of a revised document.

Apportionment

A prediction has been made of the reliability of each module in the telecommunications subsystem. This prediction was based on a count of active elements (tubes and transistors) and by assuming a ratio of these active elements to other parts. Different ratios of parts count were assumed for analog and digital circuitry. This prediction method produces a rough estimation of mean time between failures and is used when defined parts counts are not available. (See Apportionment and Studies section of this report.)

Evaluation

Preliminary evaluations have been made of temperature effects on the reliability of several modules. This evaluation will be used to better define apportionment and derating goals when equipment ambient temperatures are established.

Components

Standard Parts List. Preliminary procedures for a standard parts list have been established. The parts list will be assigned a Collins' drawing number and placed in the drawing control system. This will provide formal control and change procedures. Each of the parts list will be identified by a 265 in the last 3 digits of the part number in order to provide identification and separation from other parts in the Collins' drawing system and still maintain basic part type family numbers.

[redacted]

Four basic classifications will be assigned to individual part types:

1. Minuteman parts
2. Parts approved for Apollo with high degree of confidence
3. Parts approved for Apollo with lower degree of confidence
4. Preferred parts not yet approved

Part Derating. General guidelines for part derating have been established to aid design engineers in establishing circuit parameters and performing initial breadboard activities.

Planned Activities

The following activities are planned for the next period:

1. Apportionment. Coordinate with NAA to establish mission phase and operational function importance in order to refine the reliability requirements apportioned to each module.
2. Evaluation. Refine the reliability-versus-temperature evaluation and perform preliminary analysis of reliability versus operating time for the mission.
3. Components. Write general part category specifications and part specification format. Survey vendors for establishing an approved vendor listing. Establish a part testing program.
4. Degradation Control. Establish a training program for subcontractor design personnel. Publish reliability-versus-thermal design guidance material and publish design check lists.

Minneapolis-Honeywell

Several meetings were held with Minneapolis-Honeywell personnel on qualification-reliability test requirements and the reliability program for the stabilization and control subsystem. The initial plan was found to be too general in nature, and the subcontractor has been requested to furnish a more detailed document for approval.

Determination of reaction jet configuration for the command and service module is still in progress. The approach presently being evaluated is triple redundancy with some elements employed in simple redundancy.

One set of reaction jets would contain dual independent coils and valves with single combustion chambers. One coil receives signals from the automatic stabilization and control subsystem, and the other coil receives signals from the fly-by-wire source. A third system would be provided with completely independent fuel supply, coils, valves, and combustion chambers. This would also be a fly-by-wire system.

A preliminary reliability study was performed to evaluate horizon scanners produced by Honeywell (Los Angeles), General Electric, Advanced Technology, and Barnes. Predictions were made on the Honeywell and General Electric units only, inasmuch as the data on the others was insufficient to make a proper evaluation. The study showed that the Honeywell unit exceeded the reliability of the General Electric unit. More data has been requested from Advanced Technology and Barnes in order to complete this analysis.

Reliability predictions were made on indicators to supply astronauts with information on pressure altitude, rate of climb, and indicated air speed. This study involved three alternate configurations employing parallel redundancy. In each case a 5-hour time interval was used. Results were as follows:

1. Reliability using 3-inch standard instruments was R = 0.99999991.

2. Predicted reliability using 2-inch nonstandard instruments was R = 0.99999987.

3. Predicted reliability using a combined (three-in-one-panel) instrument, synchro-driven, was R = 0.999999.

All methods indicated a reliability equal to or greater than that predicted in the September, 1961, proposal, which was R = 0.999999.

A preliminary preferred parts list for use in boilerplate equipment was also defined during this report period.

<u>Radioplane</u>

The Radioplane earth landing subsystem Reliability Program Plan has been reviewed and approved by NAA. The test program has been reviewed and returned due to insufficient detail.

Lockheed Propulsion

A meeting was held with the Lockheed Propulsion personnel at Lockheed's Redlands facilities. A review of the Lockheed facility was conducted with favorable reactions to their testing capabilities.

Thiokol Chemical Company

Negotiations have been completed with Thiokol Chemical Company for the tower jettison motor. Thiokol has indicated confidence in meeting the stipulated reliability requirements.

TRIPS AND MEETINGS

To assure concurrence on Apollo design and test specifications, a series of discussions were held between S&ID, NASA, and subcontractor personnel during the last quarter. A listing of the discussions and the participants is presented in Table 12.

[redacted]

Table 12. Trips and Meetings

Discussion	Participants	Date (1962)
ECS work statement	AiResearch NAA/SID	22 Jan
Minuteman electronics	Dr. W. West NAA/SID	7 Feb
Project Mercury reliability	Mr. J. Kohler MAC NAA/SID	21 Feb
Preliminary design of attitude control systems	Minneapolis-Honeywell Marquardt NASA NAA/SID	28 Feb
Specification requirements with relation to cost	Marquardt NASA NAA/SID	1 Mar
Statistical Applications for qualification-reliability test plan	Minneapolis-Honeywell NAA/SID	5 to 8 Mar
Minuteman parts and application	SID Management Council	6 Mar
Environmental control system	AiResearch NAA/SID	11 Mar
Minneapolis-Honeywell qualification-reliability test plan	Minneapolis-Honeywell personnel	15 Mar
Reliability approach to program plan	Lockheed NAA/SID	21 Mar
Qualification-reliability test plan	NASA personnel	21 & 22 Mar
Lockheed coordination	Lockheed personnel	28 Mar

[redacted]

[redacted]

II. PLANNED ACTIVITIES

The results of major activities planned for completion from April through June will be reported in detail in the second Quarterly Status Report. Planned activities are delineated in the subsequent paragraphs.

DOCUMENTATION (Submitted to NASA)

Title	Due Date (1962)
Revised Reliability Plan	23 Apr
Revised Qualification-Reliability Test Plan	30 Apr
First Qualification Status List	30 Jun

STUDIES

During the April through June 1962 quarter, the following studies will be conducted.

1. Optimum implementation of alternate modes, redundancies, and in-flight maintenance provisions to be added to the spacecraft to enable the reliability requirement to be met will be determined. The constraint in this study is the fixed overall spacecraft weight. Alternate modes will include manned override and the ramification of GOSS.

2. Expansion the reliability apportionment to the black-box level will be studied.

3. Mission phase reliability and crew safety requirements in support of NASA studies will be analyzed.

4. Design reliability and crew safety analysis will be conducted in support of design reviews.

5. Reliability objectives and numerical values for proposed Apollo missions other than lunar landing and earth return missions will be investigated.

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6. Reliability subsystem interface studies will be studied based on factorial logic networks commencing with premission launch checkout and sequential regression to the subsystem and component phase in manufacturing.

7. Preliminary studies of reliability requirements for training simulators will be made. Two phases are considered: (1) equipment reliability, (2) programmed failure recognition and correction.

8. Cost versus reliability of spacecraft subsystems will be investigated.

9. Preparation of a logic diagram and reliability mathematical model for the total spacecraft will be initiated.

10. Interface wiring provisions, including the electrical connectors, will be investigated for compatibility with reliability requirements.

11. Command module to service module separation will be studied.

12. Service module to adapter separation will be investigated.

13. Parachute compartment cover release and jettison will be examined.

14. Ringsail versus extended skirt and other parachute designs will be analyzed.

15. Drogue applications will be investigated.

16. Methods of deploying main parachutes so as to obtain optimum reliability (including single versus clustered parachutes) will be determined.

17. EBW and "hot wire" methods of initiating pyrotechnic devices will be evaluated.

18. Igniter propellant will be studied.

19. Escape tower release will be investigated.

20. Liquid injection versus hinged nozzle thrust vector control will be examined.

21. Hinged nozzle versus passive nozzle thrust vector control will be analyzed.

22. Propulsion subsystem sequencer-relays versus solid-state devices will be analyzed.

23. Rocket subsystem reliability logic diagrams will be updated.

24. Preliminary failure mode analysis of rocket subsystems will be conducted.

25. Inverter trade-off will be examined.

26. Fuel cell reactant manifold will be studied.

27. Integrated radiator versus independent radiator subsystem will be analyzed.

28. Solar cell versus fuel cells will be evaulated.

29. Command module heat shield ablative material failure mode will be studied.

30. Brazed honeycomb substructure for heat shield failure mode will be studied.

QUALIFICATION-RELIABILITY TEST ACTIVITIES

The planned qualification-reliability test activities for the quarter April to June 1962 are as follows:

1. Reliability inputs to major test programs
   - Pad abort tests
   - Little Joe II launch program
   - Saturn/Apollo launch program
   - Environmental proof spacecraft
   - House spacecraft test program
   - Prequalification drop tests
   - Propulsion spacecraft tests

2. Qualification-reliability test plan revision, 30 April

3. General reliability test requirements specifications

4. Pretest analysis specification

5. Test laboratory survey specification

6. Survey of test laboratories

7. Qualification-reliability test inputs to the individual procurement specifications and specification reviews

DESIGN ANALYSIS AND REVIEWS

Design analysis and reviews for the next quarter are scheduled as follows:

Item	Date (1962)
Crew panel arrangement	Apr 4
Adapter, electronic equipment	Apr 6
Command module electrical subsystem	Apr 11
Training and simulation equipment concepts	Apr 11
Boilerplate philosophy	Apr 13
Prototype philosophy	Apr 18
Command module recovery system	Apr 20
Service module electrical subsystem	Apr 25
Telecommunications	Apr 27
Flight control system	May 2
Service module propulsion system	May 4
Command module environmental system	May 9
Command module in-flight checkout concepts	May 11
Service module environmental system	May 16
Command module reaction control	May 18
Guidance and navigation interface	Undetermined at this time
Stabilization and control	May 2
Telecommunication system	Undetermined at this time
Environmental control system GSE	
Earth landing GSE	
Launch escape GSE	
Boilerplate GSE programmed to become prototype equipment	
EBW versus "hot wire" methods of initiating pyrotechnics	

Item	Date (1962)
Parachute subsystem	
All mechanical systems	
Service module main propellant tanks	
Inner shell structure	
Heat shield honeycomb substructure	

SPECIFICATION INPUTS

The following is a list of procurement specifications that are scheduled for release from April through June. Reliability personnel will review and prepare inputs as applicable for these specifications.

Item	Scheduled Release (1962)
Circuit breaker, dc, remote control	May 1
Circuit breaker, dc, push-pull	May 1
Circuit breaker, ac, push-pull 3 phase	May 1
Circuit breaker, ac, push-pull 1 phase	May 1
Tank, helium supply	May 15
Tank, fuel supply, positive expulsion	May 15
Tank, oxidizer supply, positive expulsion	May 15
Regulator, pressure helium	May 15
Relay control	May 15
Relay power	May 15
Tank, helium supply	May 15
Regulator, pressure, helium	May 15
Valve, explosive actuator NC helium	May 15
System, propellant utilization	May 15
Valve, shutoff solenoid actuator NO, helium	May 15
Valve, shutoff, solenoid actuator NC, helium	May 15
Valve, relief pressure, helium	May 22
Valve, check helium	May 29
Valve, check oxidizer	May 29
Valve, check fuel	May 29
Connector, receptacle, pressure barrier	Jun 1

Item	Scheduled Release (1962)
Connector, plug	Jun 1
Connector, plug receptacle	Jun 1
Valve, shutoff fuel, solenoid NO	Jun 1
Valve, shutoff oxidizer, solenoid NO	Jun 1
Valve, shutoff oxidizer, solenoid NO	Jun 1
Filter, helium	Jun 5
Filter, oxidizer	Jun 5
Filter, fuel	Jun 5
Diaphragm, protective, helium	Jun 12
Diaphragm, protective, helium	Jun 12
Diaphragm, protective, oxygen	Jun 12
Diaphragm, protective, fuel	Jun 12
Wire, general purpose, interconnection	Jun 15
Wire, general purpose, high temperature	Jun 15
Valve, system isolation, solenoid NC, helium	Jun 15
Valve, system isolation, solenoid NC, fuel	Jun 15
Valve, system isolation, solenoid NC, oxidizer	Jun 15
Valve, three port, solenoid	Jun 15
Valve, shutoff manual, fuel	Jun 19
Valve, shutoff manual, oxygen	Jun 19
Valve, shutoff manual, helium	Jun 19
Valve, explosive actuator NC, helium	Jul 1
Valve, fill and vent manual, helium	Jul 1
Valve, fill and drain, manual, fuel	Jul 1
Valve, fill and drain, manual, oxidizer	Jul 1
Valve, check, fuel	Jul 15
Valve, check, oxidizer	Jul 15
Filter, helium	Aug 1
Filter, fuel	Aug 1
Filter, oxidizer	Aug 1
Valve, relief pressure helium	Aug 1
Diaphragm, burst, helium	Aug 1
Diaphragm, burst, fuel	Aug 15
Diaphragm, burst, oxidizer	
Helium Tank 9 inches and 11 inches diameter	Release dates undetermined at this time
Helium fill valve	
Quick disconnect	

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Item	Scheduled Release (1962)
Squib shutoff valve	
Filter, 10 micron	
Solenoid	
Pressure regulator 4500 to 300 psig	
Swing check valve	
Relief valve	
Positive expulsion propellant tank	
Fill valve	
Orifice	
Supercritical gas storage system	
Helium, 10-inch-diameter pressure vessel, reaction control, service module	
Helium, 9-inch-diameter pressure vessel, reaction control, command module	
N_2O_4 positive expulsion tank, reaction control, service module	
Helium, 48-inch-diameter pressure vessel, main propellant, service module	
N_2O_4 positive expulsion tank, reaction control, command module	
UDMH/hydrazine positive expulsion tank, reaction control, command module	
UDMH/hydrazine positive expulsion tank, reaction control, service module	
N_2O_4 main propellant tank, service module	
UDMH/hydrazine main propellant tank, service module	
Command module antenna heat shield	
R & D telemetry antenna	
Recovery antenna	
R & D beacon antenna	
Service module antenna	
Beacon antenna	
Telemetry radome	
DSIF omni antenna	
DSIF high-grain antenna	
Personnel communications antenna	
Automatic diagnostic in-flight test system	
Stabilization and control subsystem	
Command module to service module umbilical connector	

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RELIABILITY TRAINING AND INDOCTRINATION

Effort is continuing in the preparation of various reliability training courses. A list of the planned courses is as follows:

1. General Apollo indoctrination
2. Apollo reliability program plan
3. Computer methods of electronic design analysis
4. Minuteman standards and parts with application to Apollo
5. Design ramification in reliability apportionment and prediction (for reliability engineers)
6. Design ramification in reliability apportionment (for design engineers)
7. Qualification-reliability test plan
8. Malfunction reporting, analysis, and corrective action
9. Apollo reliability indoctrination for manufacturing employees
10. Quality control aspects of reliability
11. Apollo reliability aspects in purchasing
12. Apollo reliability indoctrination and motivation

SUBCONTRACTOR ACTIVITIES

From April through June, the reliability group will perform the following reviews and activities for subcontractor scheduled events.

General

Reliability program plan reviews
Qualification-reliability test plan reviews
Development test plan and procedures review
Witnessing initial development tests
Coordinated design reviews
Technical coordination meetings

Discussion	Participants	Date (1962)
Technical Coordination		
Preliminary contract negotiations	Aerojet-General NAA/SID	Apr 23
Method of nozzle movement	Lockheed-NASA NAA/SID	Apr 16
Approach to Apollo propulsion	Thiokol-RMD-NASA NAA/SID	
Preliminary coordination of test facilities for PFRT program	Aerojet NAA/SID	
Fuel cell qualification-reliability test plan	Pratt & Whitney	Apr 11
Stabilization and control technical coordination	Minneapolis-Honeywell	Apr 3
Heat shield ablative material	AVCO-RAD	
On-site analysis of and coordination with AVCO-RAD proposed reliability program for the heat shield ablative material	AVCO-RAD	
Review of AVCO-RAD reliability program contractural documentation	AVCO-RAD	Jun 1
On-site analysis of AVCO-RAD reliability program	AVCO-RAD	
Contract negotiations on tower jettison motor	Thiokol/NAA-SID	Apr 6
Technical coordination meeting - AiResearch environmental control system	NASA/SID	Apr 12

Discussion	Participants	Date (1962)
Reliability apportionments Guidance and navigation subsystem	MIT-NASA NAA/SID	Apr 18
Reliability program plan	Pratt & Whitney NAA/SID	May 1
Qualification-reliability	Pratt & Whitney NAA/SID	Apr 5 & 6
Technical coordination meeting	Pratt & Whitney NAA/SID	Apr 20
Reliability	Collins Radio NAA/SID	May 3
Review test facilities	Northrop-Ventura NAA/SID	
Periodic design reviews	Northrop-Ventura NAA/SID	
Cost analysis of special tanks	Minneapolis-Honeywell NAA/SID	
Facility plan	Minneapolis-Honeywell NAA/SID	
Witness initial development tests	Pratt & Whitney NAA/SID	
Review test facilities	Pratt & Whitney NAA/SID	
Design apportionments and failure mode analysis	Pratt & Whitney NAA/SID	
Documentation		
Review test plans	Northrop-Ventura NAA/SID	

Discussion	Participants	Date (1962)
Qualification-reliability test plan review	AiResearch NAA/SID	
Test plan	Minneapolis-Honeywell NAA/SID	
Reliability test plan for fuel cells	Pratt & Whitney NAA/SID	Apr 5 & 6
Associate Subcontractors		
Reliability apportionments	NASA/SID/MIT	Apr 18
Guidance and navigation subsystem	NASA/SID/MIT	
Source Selection		
Super-critical gas storage system		
Command module and service module titanium high-pressure helium tanks		
Command module and service module fuel and oxidizer reaction control tanks		
Service module main propellant fuel and oxidizer tanks		